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 UNCERTAINTY AND POLICY RECOMMENDATIONS(U) RAND CORP
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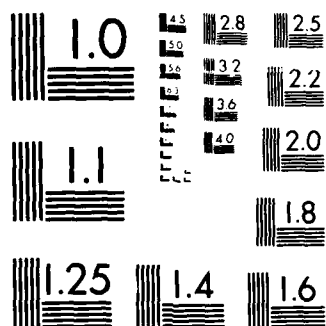
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A RAND NOTE

AD-A200 492

**Tactical Dispersal of Fighter Aircraft:
Risk, Uncertainty, and Policy Recommendations**

John M. Halliday

February 1987

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→ This Note examines U.S. Air Force policy on the basing of tactical fighter aircraft. Specifically, it addresses the risks of losses to both aircraft and sorties that are implicitly accepted by commanders and policymakers when they base fighters within range of potential attackers. It also deals with one potential alternative to the current static basing mode--tactical dispersal--and with the organizational impediments to it. The author applies the concepts of risk and uncertainty to plausible attack scenarios for main operating bases and dispersed sites, and he discusses policy issues that must be addressed if high sortie rates are to be sustained during the early days of a conflict. He recommends that a program be designed to empirically test the assumptions used in the models for evaluating basing policy. *Keywords*

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**Prepared for
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PREFACE

Tactical fighter aircraft currently in use by the U.S. Air Force are dependent on the continuous availability of large, complex main operating bases (MOBs) to sustain the high sortie rates that would be demanded in the event of conventional combat. These MOBs appear to be increasingly vulnerable to attacks by a Soviet Air Force that is becoming larger and more capable over time.

There is no high-level direction for a coordinated consideration of alternative basing options. The Air Force position is based on the assumption that MOBs can be made survivable, and that one possible alternative, dispersal of fighters to smaller fields, is too risky. Such positions are difficult to change in the face of common organizational impediments.

This Note addresses the concepts of risk and uncertainty and applies them to plausible attack scenarios for MOBs and dispersed sites. It deals with policy issues that need to be addressed if high sortie rates are to be sustained during the early days of a conflict. The findings should be of interest to policymakers in DCS/Plans and Operations, DCS/Logistics and Engineering, DCS/Research, Development, and Acquisition, and other Air Staff offices concerned with the design of new aircraft; to logisticians; and to tactical commanders whose wartime capabilities would be affected by both the aircraft they fly and the bases they fight from.

This work was done under a concept development study effort for Project AIR FORCE in RAND's Resource Management Program.



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SUMMARY

This study examines U.S. Air Force policy toward the basing of tactical fighter aircraft. Specifically, it addresses the risks of losses to *aircraft* and *sorties* implicitly accepted by commanders and policymakers when they base fighters within range of potential attackers. It deals with tactical dispersal, one potential alternative to the current static basing mode, and with the organizational impediments to it. Examination of the viability of the current basing posture is especially timely for several reasons:

- Attackers often initiate hostilities by attempting to negate the adversary's airpower.
- The character of the Soviet Air Force has changed so dramatically over the past decade that the potential threat to NATO airfields should be perceived as being very serious.
- The U.S. Air Force is in the initial stages of the development of a new fighter; its support characteristics will influence U.S. capabilities well into the next century.

The current aircraft/base structure is not the result of any conscious design but rather is the consequence of an evolutionary process. Unfortunately, modern fighter aircraft are almost entirely dependent on the continued operation of large fixed airbases. Since World War II fighters have generally become more dependent on hard, smooth surfaced runways; these are required because of the extremely high tire pressures in aircraft such as the F-15 or F-16. Smoothness is required because the landing gear struts cannot absorb variations in the surface at high speed without transmitting the loads thus generated to the airframe. Aircraft repair characteristics have also become vastly more dependent on extensive base facilities.

A unique feature of this study is that it deals with the uncertainties inherent in the analysis of airbase attack by breaking down the task of attacking into individual sources of uncertainty,

assigning probability distributions and predicting the range of consequences resulting from those distributions in terms of sorties produced and surviving aircraft. The first five days of a conflict are examined using a probabilistic simulation model. The enemy attacks airbases on three of the five days. The size of the initial attacking force is parameterized at one and two regiments against each 72 aircraft USAF wing.

The dispersal alternative examined here involves the removal of 32 of the wing's 72 aircraft from the main operating base (MOB). These 32 would be divided into four groups of eight, each group occupying one of ten possible sites available to each MOB. Petroleum, oil, and lubricants (POL) would be supplied by truck operating from Central European Pipeline System (CEPS) refueling points. Munitions would be trucked from storage points such as U.S. Army Ammunition Supply Points.

This concept considers dispersed operating locations (DOLs) as complementary to MOBs rather than as replacements for them. The MOBs remain as integral parts of this basing scheme for several reasons. First, the MOB is likely to remain a hard target requiring numerous sorties to close. Next, the maintenance concept of operations would be to recover aircraft with significant maintenance problems or battle damage at the MOB where the extensive facilities and large pool of personnel could better handle repairs. Finally, in the long run, the presence of the two types of operating locations gives the Soviets more difficult choices to make in the development of their combat systems.

The table below provides the results for the runs that include the treatment of uncertainty. Detection, penetration, weapons delivery, and number of aircraft on base at the time of the attack are all represented by probability distributions. The MOB/DOL configuration appears superior; however, the situation is much less certain when the variance involved is considered. A commander gets only one trial; not the 200 of a simulation. It seems plausible that one could judge these outcomes as roughly equivalent, especially so if one is more sanguine about the level of protection provided by shelters on MOBs. However, when the uncertainties of runway repair are taken into consideration, the risks associated with reliance on MOBs only for the continued operation of fighter aircraft are considerably higher than might have been previously expected, whereas the risks of tactical dispersal are somewhat lower.

These analytic findings may have some impact within the Air Force if some natural organizational impediments can be overcome. As in any large, complex organization, large policy shifts within the Air Force normally require coalition action from among several specialized groups. Fortunately, the growth of the Soviet threat has been recognized, thus injecting uncertainty into the tactical forces' ability to sustain combat operations. This uncertainty is a precondition to the process of coalition building. As predicted, the service's response has been to strengthen standard operating procedures; that is, bases in USAFE have been toned down, hardened, and otherwise made more combat serviceable. The hope is that analysis such as that contained in this study can serve to provide further evidence of uncertainty which, organization theory predicts, will assist in coalition building necessary to initiate a comprehensive search for alternative solutions such as tactical dispersal.

The specific policy recommendation of this Note is that a program be designed to empirically test the types of assumptions used to drive the models employed in evaluating basing policy. Items to be tested would include:

Table S.1
EFFECTS OF UNCERTAINTY ON SORTIES
AND AIRCRAFT LOST

Basing	Attack Size	
	One Regiment	Two Regiments
MOB	5300/16 12/2.6	5220/46 sorties/std dev 23/5.9 kills/std dev
MOB/DOL Aircraft in open	5330/36 9/4.4	5300/49 sorties/std dev 13/5.7 kills/std dev
MOB/DOL Revetments	5350/20 6/2.4	5320/33 sorties/std dev 10/3.7 kills/std dev

- The ability of the civil engineering community to conduct Rapid Runway Repair operations on enough real craters to establish reasonable confidence in their capability. These craters should be the product of weapons dropped from the air and should include craters produced by Soviet weapons, if possible, as well as the likes of JP 233, BKEP, and STABO.
- The degree of protection provided by shelters against current and potential threat weapons.
- Clearance techniques for sophisticated minefields.
- Detection of DOL type operations in environments similar to Central Europe.
- Penetration to DOL sites in the face of active defenses (best accomplished during realistic exercises such as Red Flag).
- The delivery of weapons on DOL targets in operationally realistic conditions.

How to base aircraft in the future is such a fundamentally important question to the Air Force that the expenditures implicit in these recommendations are not unreasonable. Without such hard data it is not likely that a strongly held belief, such as the viability of the current basing posture, can be successfully challenged. The Air Force is in the early stages of the development of a new generation of fighters; resolving basing issues now could greatly influence the design of new fighters.

ACKNOWLEDGMENTS

This research was undertaken both as a component of RAND's Project AIR FORCE Resource Management Program and as a dissertation submitted to The RAND Graduate School (RGS) in partial satisfaction of the requirements for a doctoral degree in public policy analysis. My dissertation committee included Michael Rich, chairman and then Resource Management Program director; Morton Berman, project leader during my years at RAND; and Kenneth Solomon, the inspiration for my analytic focus. Each of these has contributed in his own special way to whatever success I have had in this effort.

My interest in this area of analysis--airbase survivability--is the product of a long association with RAND colleagues Donald Emerson and Felix Kozaczka. I owe them a great deal for providing the questions, the insights, and the tools to deal with these issues. Finally, my wife Patricia deserves special mention for all the support and understanding she provided during my entire time at RGS.

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GLOSSARY

ABA	Airbase Attack
AFSC	Air Force Systems Command
AFLC	Air Force Logistics Command
AIDA	Airbase Interdiction Damage Assessment
ALCM	Air Launched Cruise Missile
ALRS	Alternate Launch and Recovery Surface
ATF	Advanced Tactical Fighter
AWACS	Airborne Warning and Control System
BKEP	Boosted Kinetic Energy Penetrator
CBU	Cluster Bomb Unit
CEPS	Central European Pipeline System
COB	Collocated Operating Base
CONUS	Continental United States
DOL	Dispersed Operating Location
EOD	Explosive Ordnance Disposal
FEBA	Forward Edge of the Battle Area
LCOM	Logistics Composite Model
LOC	Lines of Communication
MAC	Military Airlift Command
MCL	Minimum Clear Length
MCW	Minimum Clear Width
MILS	Milliradians (an error of approximately 1 ft per 1000 ft in range)
MOB	Main Operating Base
MOS	Minimum Operating Surface
PAA	Primary Assigned Aircraft
POL	Petroleum, Oil, and Lubricants
OCA	Offensive Counter Air
RAF	Royal Air Force
RRR	Rapid Runway Repair
SAC	Strategic Air Command
SAM	Surface-to-Air Missile
SHORAD	Short Range Air Defense

STOL	Short Takeoff and Landing
STOVL	Short Takeoff Vertical Landing
TAC	Tactical Air Command
TAGS	Theater Air-Ground Simulation
TSAR	Theater Simulation Of Airbase Resources
TSARINA	TSAR Inputs to AIDA
USAFE	United States Air Forces in Europe
USMC	United States Marine Corps

I. INTRODUCTION

Since all information and assumptions are open to doubt, and with chance at work everywhere, the commander continually finds that things are not as he expected.

Carl von Clausewitz, 1832

To what extent has mainstream U.S. air doctrine preeminently envisaged aerial warfare as a vast engineering project whose details could, in every important respect, be calculated as precisely as the stress loadings on a dam or the tensile strength requirements for a bridge?

Lt. Col. Barry Watts

PURPOSE

This is a study about the policy of the U.S. Air Force regarding the basing of tactical fighter aircraft in Europe. Specifically, it addresses the risks of losses to aircraft and sorties implicitly accepted by commanders and policymakers when they choose to base fighters within range of potential attackers. It deals with tactical dispersal, which is one potential alternative to the current static basing mode employed by the U.S. Air Force, and the organizational impediments to it. The study seeks to illuminate these issues and provide evidence to support the resource allocation needed to improve our understanding of basing and airframe design decisions.

Basing policy is unusual for at least two reasons. First, although bases are both logistically and operationally significant as large consumers of resources and critical components related to airpower, basing is a policy orphan. By this I mean that no single organization within the Air Staff or the Air Force at large is responsible for devising basing policy. Although this status is not unique to basing policy, it is unusual given its pervasive influence and importance.

The second unusual characteristic of basing policy is that many of its critical components are outside the control of the Air Force planning community. National objectives, politics, and foreign policy each play a significant part in basing. Policymakers and planners, both

within the Air Force and outside, are mutually constrained by the realities of technology, geography, military power, and the sovereign prerogatives of allied nations.

Reconsideration of basing issues is especially important at this time because, as outlined by Rich et al. (1984): "The distribution, quality, and size of the threat are making the environment within which U.S. forces must operate more stringent and less predictable with respect to

- the time they will have to respond to enemy action
- the location of potential conflicts
- the size and composition of adversary forces
- the availability and extent of support facilities, and
- the exposure of those facilities to enemy action."

As is to be expected in dealing with an important policy issue such as tactical dispersal, a number of technical facets are embedded within the topic that cannot be ignored by decisionmakers. Some of these issues are:

- Tactics--When should commanders employ dispersal in light of perceived enemy intelligence capabilities? Should all bases behave alike? At what level should these decisions be made?
- Command, control and communication--What information must be transmitted to dispersed assets? What technologies are available? How are analogous dispersals (e.g., Harriers, Army helicopters) being handled?
- Air vehicle design--What equipment can be incorporated into the airframe design to make it more self supporting? What is the weight penalty that must be paid to make aircraft better able to disperse?
- Manpower, personnel and training--How must the acquisition, training, and assignment of officers and airmen change?
- Organizational--Is the current structure suited to a change in basing policy? What institutional impediments exist to implementation?

- Geopolitical--Can commanders rely on host nations to provide immediate access to dispersal sites in times of crisis?
- Economic--Are the costs involved in a feasible range? Who will pay?

It is not the intent of this study to examine each of these issues, several of which are addressed in an integrated approach by Berman et al. (1985); the intent rather is to focus on the risks of current policy compared to one plausible alternative, and certain organizational issues surrounding consideration of that alternative.

AIRPOWER LIMITED BY AIRBASE AVAILABILITY

As of late 1984 the International Institute for Strategic Studies credited the U.S. Air Force with approximately 2,100 tactical fighter aircraft. This fleet was composed primarily of 380 F-15s in an air superiority role, 460 dual mission F-16s, 100 F-4G Wild Weasel surface-to-air missile (SAM) hunters, 230 deep strike F-111s, and 290 A-10 close air support aircraft. The remaining 600 aircraft are largely older model F-4s and A-7s, most of which are programmed to be replaced in the near future. In peacetime approximately 500 of these are assigned to bases within NATO, somewhat more than half that number to Pacific bases, and the remainder within the continental United States and Alaska.

Such numbers of highly capable aircraft, crewed by well trained and disciplined flyers, represent a truly impressive amount of military power. They endow a commander with the potential ability to deliver powerful blows to enemy forces with the sort of timing and flexibility only airpower can provide. Unfortunately these aircraft, with the partial exception of the A-10, are almost entirely dependent on the continued operation of large fixed airbases. Without their bases today's aircraft are simply not capable of sustaining combat operations for both operational and logistical reasons. One measure of this dependence can be seen in Table 1.1 below, which gives runway requirements for several current tactical fighters.

Table 1.1

AIRCRAFT OPERATING SURFACE REQUIREMENTS

(Nominal combat weight on dry runway)

Aircraft	Combat Takeoff Weight (lb)	Takeoff Distance (ft)	Landing Distance (ft)
F-15	55,000	900	3,500
A-10	32,711	1,450	1,300-2,000
F-4	41,487	3,180	3,100
Tornado*	50,000	3,000	1,215

*Operated by the United Kingdom, Federal Republic of Germany, and Italy.

This table illustrates that, with the exception of the A-10, approximately 3,000 ft of clear runway surface is necessary to continue operation of these aircraft. Add to these minimum lengths some allowance for dispersion about the nominal touchdown point as a result of variations in pilot performance and potential weather problems, and the realistic minimum operating surface can increase significantly above the minimums shown (perhaps 6,000 ft). In addition, it is important to realize that takeoff and landing surfaces must be relatively smooth, so smooth that it is difficult to meet approved roughness criteria when attempting to make repairs using current Rapid Runway Repair (RRR) techniques.

EVOLUTION OF AIRBASES

The aircraft/base structure of today is not the result of any conscious design but rather is the consequence of an evolutionary process that has been influenced by five mutually reinforcing factors:

- The tactical environment faced by the USAF has been predominantly benign with respect to threats to airfields. Generally U.S. tactical airpower has enjoyed a position of

superiority relative to its enemies which, coupled with a richness of resources, obviated any need to be deeply concerned with possible threats to its support facilities. This environment was present during the Army Air Corps days of World War II and persisted through the Korean War and Vietnam.

- In the 1950s NATO adopted a strategy, contained in NATO Military Committee Document 14/2, of large-scale retaliation. This so called "Tripwire Strategy" envisioned only a single nuclear launch from airbases, not the sustained sortie generation ability required by MC 14/2's replacement. The "Flexible Response" of MC 14/3 was adopted in 1967, but the airbases were well established by then.
- Large organizational and physical structures tend to be inherently more efficient in the economic sense than smaller more self sufficient entities. Thus drives to hold down defense costs introduced a bias toward large base structures to take advantage of economies of scale.
- Military organizations are noted for their top-down control mechanisms. Such hierarchical structures are more easily maintained when they are located in close geographic proximity. Again a bias is introduced that favors large airbases.
- For both valid military reasons and the inability of the support community to demonstrate operational payoffs, the primary measures of merit for new aircraft systems have related to air vehicle performance characteristics. Generally, and most especially in the past, this has led to a reluctance to incorporate anything into the air vehicle that could be left on the ground at a supporting base, since added weight and space would result in degraded performance. The difficulty involved in suggesting that performance can be held constant while still adding some nonflight-related attribute to the airframe is that airframe performance is treated as a vector, not as a goal. It can always be a little better without that extra weight or drag that might help its support characteristics.

REASONS FOR CONCERN

For three reasons this dependence on airbases should concern military and civilian policymakers:

- The initiation of hostilities is often an attack on the adversary's airpower. It is therefore critical to try to protect both the aircraft and the sortie early in a conflict.
- The character of the Soviet Air Force has changed so dramatically over the past decade that the potential threat to NATO airfields should be regarded as very serious.
- The U.S. Air Force is in the initial stages of the development of a new fighter, the support characteristics of which will influence U.S. capabilities, both in NATO and in other potential areas of conflict, well into the next century.

These three factors, although pointing to a possible need to reevaluate aircraft/airbase policies, do not in themselves justify change. Air Force leaders are aware of the problem; as General Billy M. Minter, recently retired commander of USAFE, expressed the dilemma regarding airbases (Kyle, 1984):

It's not difficult to say that they [the airbases] are vulnerable; it's difficult to say how vulnerable. Organizations like the Rand Corporation have done a lot of research for us, and they give vulnerability estimates based on modeling and simulations [that show] we are going to suffer damage in excess of 40% of our support facilities. It gives me a lot of trouble.

However, leadership is understandably reluctant to alter approaches that have worked in the past for an untested alternative. This study hopes to provide evidence to reinforce the view that policies regarding the basing of tactical fighters in a potentially hostile environment must be reviewed.

ONE RESPONSE

One frequently mentioned alternative to complete dependence on large fixed bases in the theater of operations is temporary dispersal from such bases. The purpose of this study is to compare the risks of such a change in policy to the implicit risks of maintaining the status quo. Examinations of dispersal are of course nothing new. The difficulty with conventional approaches to such studies is that they tend to be driven by assumptions that often fail to recognize uncertainties, and most especially by the assumptions that deal with the enemy's ability or intent to attack dispersed sites. The problem is well expressed by Roy Boot, retired Executive Director, New Aircraft of British Aerospace Aircraft Group, Warton Division (Boot, 1984):

Which level of agility and speed range is necessary to meet this criterion, and which features have to be built in to ensure continued operation in the combat zone (e.g., STOL or STOVL), dispersibility, etc., remain highly contentious subjects. Systems studies to resolve the questions continue unabated, but in the author's opinion, more often than not the answers are so dependent on the assumptions made that his [the author's] 1980 definition 'that operational analysis is the calculation of assumptions to validate predetermined conclusions' is often nearer the truth than one would like.

A unique feature of the present study is that it deals with the uncertainties inherent in those critical assumptions by breaking down the task of attacking a dispersed site into individual sources of uncertainty, assigning probability distributions and predicting the range of consequences resulting from those distributions in terms of sorties produced and surviving aircraft. The probability distributions were selected through interviews with operational commanders, R&D managers, and functional technical experts. Although no technique can hope to eliminate assumptions, the author feels that this approach has succeeded in highlighting their influence.

THE NOTIONS OF RISK AND UNCERTAINTY

The use of probability distributions rather than point estimates or, as is usually the case in studies of dispersal, certainties allows an analyst to recognize and deal with the existence of uncertainties as distinct from risk. James P. Kahan provides a technical distinction between risk and uncertainty (Kahan, 1979):

If a decision maker's (DM's) choice uniquely determines the consequences, then we speak of decisionmaking under certainty. If, on the other hand, consequences occur, given a choice, with a known (or estimable) probability, then we speak of decisionmaking under risk. Finally, if we don't (or can't) know the probabilities, then we speak of decisionmaking under uncertainty.

Abe Kaplan's description provides more of a "gut feel" (Kaplan, 1963):

We face risk when we have knowledge of a law that operates but involves a random element. We are given a probability, but what the outcome will be in the case before us remains uncertain. The other type of uncertainty may be called statistical ignorance: here we do not know what law is operative. We are ignorant, not necessarily of all circumstances, but of enough of the significant ones so that we cannot assign a determinate probability to possible outcomes. The difference between these two sorts of cases is illustrated by the decision that must be reached if we find ourselves in a card game with strangers (excluding the rational decision not to play at all): there is an element of risk intrinsic to the game, and a quite different element of statistical ignorance about the players - their skill, their style, and, of course, their honesty.

ROLE OF UNCERTAINTY

The object of dispersal is to present the enemy commander with a situation containing, in his mind, a considerable amount of uncertainty regarding his ability to suppress U.S. airpower. Dispersal, therefore, should help deter conflict in the first place or, failing that, should tend to cause the enemy commander to ignore airbases as a profitable target set. To use Kaplan's analogy, we want him to make the "rational decision not to play the game at all."

As in playing poker, so too should military commanders want to know their potential adversary's attitude toward risk. Adomeit cites three noted Sovietologists as essentially agreeing that the Soviets have the following operating principles (Adomeit, 1982):

(1) Soviet leaders act according to the proverb, "If you don't know the ford, don't step into the river." They do not plunge into contests blindly; they rarely gamble, unless they feel the odds are overwhelmingly in their favor.

(2) Soviet leaders are quite prepared to pull back when resistance on any one sector of the enemy front turns out to be stronger than anticipated: there are always other sectors which are less staunchly defended and where one's force can be applied to better advantage.

However, we must first assure ourselves that we are not in fact doing just the opposite, that is, presenting him with a soft, lucrative, easy to disrupt target set.

ORGANIZATION OF THE NOTE

This Note describes the methodology used to do the risk and uncertainty analysis, applies it to a plausible conflict scenario, and outlines some institutional difficulties inhibiting consideration of alternative basing modes. Section II provides some historical background, which serves to illustrate the longstanding nature of threats to airbases. In Sec. III the nature of the target and the threat is explored. Section IV outlines the theoretical basis for the analytical technique used in Sec. V. Finally the study is concluded in Sec. VI with a discussion of organizational considerations and recommendations for further work in the area.

II. HISTORICAL BACKGROUND

The plane is a strange creature. In the air, refuelled, armed and piloted by a good flyer, it represents an incarnation of power and fighting ability that strikes fear into tanks and ships at sea....But the plane, so powerful in the air, is a despicable object on the ground. Not only is it harmless, it lacks the most minimal defensive capacity. It squats on the runway, clumsy and prostrate, at the mercy of any enemy. Not only is it vulnerable to air attack (which makes air-bases attractive targets in war), but even some humble mortar, correctly deployed, can tear it to pieces. It costs a fortune, it can decide the fate of a war, and yet, it's as helpless as a baby.

Ezer Weizmann
Chief of Staff of the
Israeli Air Force
1967 Arab-Israeli War

INTRODUCTION

The goal of airbase attack is to negate enemy airpower by denying him the ability to generate sorties in a timely manner. This can be accomplished either by the direct killing of aircraft or by the long-term disruption of his ability to generate sorties. By 1939 the growth of aircraft as a military force had reached sufficient maturity to warrant explicit consideration of means to deliver a devastating blow to enemy airpower at the initiation of hostilities. The most efficient way to deal with enemy airpower, given the advantage of being the aggressor, is to catch the enemy on the ground before he knows a war has begun, or, at least, before he assumes a wartime alert posture, and to continue applying pressure for as long as is deemed advantageous to do so. The purpose of this section is to highlight the fact that this logic has indeed been vigorously pursued since 1939 and to look at some historical responses to airbase attacks.

POLAND 1939

On 1 September 1939, Nazi Germany launched an attack on Poland without a declaration of war. Conflict was initiated with combined land, sea, and air attacks. Of primary interest to the Luftwaffe, Germany's air force, was the destruction of the Polish air force through airfield attacks. Germany entered the fight with approximately 2,000 warplanes to Poland's 935.

Contrary to initial German reports, the Luftwaffe failed to destroy the Polish aircraft on the ground. According to F. Kalinowski, a Polish major and later an RAF Wing Commander (Bekker, 1968):

The German Luftwaffe did exactly what we expected. It attacked our airfields and tried to wipe out our aircraft on the ground. In retrospect it seems quite naive of the Germans to have believed that during the preceding days of high political tension, and with their own obviously aggressive intentions, we would leave our units sitting at their peacetime bases. The fact of the matter is that, by August 31st, not a single serviceable plane remained on them. In the previous forty-eight hours all of us had been transferred to emergency air-strips. As a result, the Germans' opening air blast completely failed in its purpose....

Later analysis by Luftwaffe intelligence confirmed that German destruction of hangars and runways had contributed nothing, and that all aircraft destroyed on the ground during the initial attacks were obsolete.

BARBAROSSA-RUSSIA 1941

The results of the next surprise attack by the Luftwaffe, at the start of hostilities against the Soviet Union, were considerably more favorable to the attacker. Quoting Nicholas Bethell (Bethell, 1977):

At approximately 3:00 a.m. "suddenly came a roar like thunder" as 6000 German guns began bombarding Red Army defense posts, supply dumps and barracks all along the border. At the same time Luftwaffe aircraft swarmed out of the western sky, dropping their bombs on both military and civilian targets, but concentrating on airfields. By midday the Luftwaffe had knocked out 1200 Russian warplanes-800 of them on the ground-while losing only 10 of its own.

PEARL HARBOR-UNITED STATES 1941

In early December of 1941 airpower was again a primary target when the Japanese launched 353 aircraft from six carriers for the Pearl Harbor raid. Not only was the naval base at Pearl Harbor attacked but also military installations dispersed throughout the island of Oahu. During the Pearl Harbor attack a total of 132,200 kg of ordnance was delivered by the 353 attacking Japanese planes; 41,000 kg of that sum was dropped on airfields. (Using *Air Force Magazine* estimates of ordnance loads, 17 Su-24 Fencers could deliver the entire Pearl Harbor tonnage themselves. Alternatively, 21 MIG-27 Flogger-Ds could theoretically deliver the airfield tonnage.) This force killed 2,403, wounded 1,178, sunk or seriously damaged 18 ships, destroyed 188 of 394 aircraft and damaged 159. The Japanese lost one fleet submarine, five midget submarines, and 29 planes (Prange, 1981).

EGYPT 1967

At 0745 hours on 5 June 1967, Israel carried out a preemptive strike against ten Egyptian airfields. The Israelis had 196 operational aircraft at that time; of these, only four were held in reserve for air defense. The primary weapon of the attacking force was the aerial cannon because the low-level penetration required for surprise also required high fuel consumption rates at low altitude and therefore light bomb loads. The bombs carried were used to close runways temporarily to keep the Egyptians on the ground and make them easy strafing targets. The initial attack, which had been in planning for five years, consisted of three waves of four aircraft against each airfield. Each flight of four spent between seven and ten minutes over the target. Rapid turnaround permitted aircraft to be back over the target within one hour, with the result that the Egyptian fields came under repeated attack for approximately three hours. Churchill credits the Israelis with employment of a rocket-boosted runway cratering bomb and the use of conventional bombs with delayed fuses to preclude the rapid repair of runways. In addition, the Israelis launched harassing strikes during the night to further hamper recovery operations. By nightfall of the second day, the five Arab states involved in the conflict had lost 416

aircraft of which 393 were ground kills. Israel lost 26 planes, 19 of these in the attacks against Egypt (Churchill, 1967).

RESPONSES

The types of actions nations have taken in response to airfield attack, or the threat of such attack, have varied greatly and seem dependent on the perceived degree of threat. Six approaches have been employed: rearward basing, hardening, active defenses, deception, launch on warning, and dispersal. No single approach is perfect nor necessarily applied independently of other approaches. Each does have points in its favor; this suggests a mixed strategy of the type investigated in this Note.

Rearward Basing

This is perhaps the most simple response. The idea is to remove ones forces from danger by basing beyond the range of enemy aircraft. It was successfully used by the British during the Battle of Britain when those elements of the RAF not directly involved in the battle were moved to bases that could not be reached by the Luftwaffe. USAF basing in Thailand during the Vietnam era could also be considered at least partially of this type. Warning and response time can be expected to improve for the defenders. However, the utility of this approach is limited because of the Soviet's introduction of air-to-air refueling techniques and longer-range aircraft. Even more important are the problems of responsiveness and sortie turnaround; if one's forces are based to the rear they are not readily employed in a timely manner, nor can they generate as many sorties as might be possible for units nearer the battle.

Deception

During one phase of the Battle of Britain, the Luftwaffe devoted a great deal of effort to airfield attack. In an attempt to protect its bases, the RAF adopted a novel strategy of pairing each active fighter base with one or more decoy airfields; eventually hundreds of these decoys were built. The program, directed by Sir John Turner, began with simple lighting systems designed to simulate emergency landing fields

and to draw off the night attacks to which the RAF was especially vulnerable. The Luftwaffe pilots proved eager to drop their loads on these inviting targets. Next, suitably timed fires were lit at the decoy bases, lest the attackers be discouraged by a lack of results. To prevent compromise by daytime reconnaissance of the supposedly bombed main fields, they were supplied with wrecked airframes, damaged buildings, and canvas bomb craters.

The final step in Britain's campaign of deception was to add bogus airfields that looked authentic enough to draw daytime attacks. These were supplied with decoy aircraft, hangars, and ground crews whose function was to simulate activity for the enemy's benefit. Each daytime dummy field was under the direction of a flight officer located at the home "real" base. Seymour Reit provides insight into their operation (Reit, 1978):

The men lavished much attention on their spurious bases, and sometimes became highly incensed when Luftwaffe planes flew in to attack, forgetting of course the purpose for which the sites were designed. A memorable exchange, recounted by Flight Lieutenant Robin A. Brown, took place over a K-Area field telephone between a flight sergeant and his pilot officer. The conversation went on against a loud background of exploding bombs and hammering machine guns:

Flight Sgt. (agitated): Sir! We're being attacked!
Pilot Officer: Splendid, Sergeant. Good show.
Flight Sgt.: They're smashing the place to bits!
Pilot Officer: Yes, excellent. Carry on.
Flight Sergeant: But, sir--we need fighter cover!
They're wrecking my best decoys!

The success of these decoys was a matter of deadly serious business to the Luftwaffe and the RAF. The dummy airfields alone drew over 440 enemy raids, compared to about 430 on the operational Fighter Command fields. However, deception can only serve to augment other approaches; it cannot stand alone.

Hardening

This is the practice of providing passive defenses to potential targets to make them more difficult to damage and thus to render them less desirable as targets. It consists of such activities as the use of protective shelters for aircraft, hardening of critical buildings, making provisions for detection and recovery from chemical attack, toning down the painting of the airbase, etc. This tactic was successfully employed by the Egyptians and the Israelis after the dramatic 1967 attacks and is currently being practiced by the United States and many of its NATO allies, as well as by the Soviet Union. Hardening has the disadvantage of being inflexible with regard to location; it also presents the enemy with a known target set against which he can design specialized weapons and tactics.

Active Defense

This is a strategy of raising the cost to the attacker, ideally to the point that he will decide to forgo airbase attacks altogether. Active defense combines both area defense weapons, such as the Hawk belt and F-15s, with point defenses like Rapier and Stinger. This method is used to some degree by both the Warsaw Pact and NATO air forces. At the heart of the airbase survivability problem is the ability of attacking forces to cause defenders to spend disproportionately large sums to counter rather inexpensive threats.

Launch-on-Warning

Under this response, the base about to be attacked attempts to launch a significant number of its aircraft to evade the enemy. The manned bomber force of the Strategic Air Command (SAC) relies on this technique, coupled with dispersal, for survival. It is obviously dependent on the ability to detect an incoming attack and to issue timely launch orders. This tactical response can serve to lessen the consequences of attacks but cannot help guarantee an operational airfield to return to.

Dispersal

The idea behind this strategy is to present a much diluted target set to the enemy by limiting the number of aircraft at one location. As indicated above, the German attack on the Polish air force failed despite vastly superior numbers and equipment because of the successful early dispersal of the Poles' aircraft before hostilities. The Luftwaffe later adopted a dispersed mode of operation themselves in response to vastly superior allied airpower. Aircraft of this era, however, were notably better suited to dispersed operations than most modern fighters because of their relatively simple designs and minimal runway requirements. Dispersal increases the chance that surviving aircraft will have a facility to operate from, but, depending on the degree of protection provided to the aircraft on the ground, it can expose fighters as soft targets on the ground.

III. AIRBASES AND AIRBASE ATTACK

If I am able to determine the enemy's dispositions while at the same time I conceal my own then I can concentrate and he must divide. And if I concentrate while he divides, I can use my entire strength to attack a fraction of his. There, I will be numerically superior. Then, if I am able to use many to strike few at the selected point, those I deal with will be in dire straits.

Sun Tzu
The Art of War

INTRODUCTION

To better appreciate the issues treated in this Note it is important to understand that an airbase is a part of a sortie generation system rather than simply a collection of personnel and facilities. A base can be viewed as being made up of four interactive components that together work toward the goal of delivering airpower where, when, and in whatever quantity is required. These components are the physical plant and equipment (including consumables such as fuel, food, and weapons), the people, the command and control system, and finally the aircraft. (Actually, the delivery of airpower goes considerably beyond the resources of a single base, this being especially true for missions requiring penetration to the enemy's rear area.)

THE PLANT

A nominal U.S. main operating base in Central Europe has a single 10,000 ft runway with an 8,000 ft parallel taxiway. The taxiway is usually designated as an emergency runway for wartime use. Recently a program has been instituted to build limited duty Alternate Launch and Recovery Surfaces (ALRS) for use in the event the main surfaces are interdicted. ALRS are shorter and less durable than standard runways. There are usually enough hardened aircraft shelters to provide protection for all the wing's aircraft. These shelters protect against strafe, cluster submunitions, and near misses by general purpose bombs. They are also used to disperse maintenance shops and supply assets by

getting them out of soft buildings and reducing the chances of losing all of a particular repair capability or supply item. Squadron operations buildings as well as the Wing Command Center are also hardened facilities that protect against chemical threats as well as conventional weapons. The remaining facilities are hardened in a nonuniform manner; some are soft, some make do with sand bags, and others have been revetted. In all, the industrial area of a base, exclusive of takeoff and landing surfaces, might cover an area of 2,000 ft by 12,000 ft and contain approximately 70 conventional structures and 60 to 80 aircraft shelters. Fuel requirements provide some idea of the magnitude of consumable resource requirements (Bowie, 1984):

an F-15 with Fast Pack conformal tanks carries about 3,200 gallons of JP-4 grade fuel, a mixture of naphtha and kerosene. Assuming an operationally ready rate of 80 percent in theater and two sorties per day that use up all but 5 percent of each aircraft's fuel, a squadron would require 115,520 gallons per day, or 3,465,600 gallons per month. A wing of F-15s under the same conditions would require 10,396,800 gallons of fuel per month. Such a quantity would cover a football field to a depth of 48 feet in JP-4 and require about 1,660 truck deliveries per month or 561 rail tankers per month.

THE PEOPLE

Each base is of course unique, its actual population depending on the particular type of aircraft it hosts and the presence of a higher headquarters or tenant units. However, one can generally expect to find approximately 4,500 people assigned to a basic MOB. Of these, 2,000 would be attached to three fighter and three maintenance squadrons plus the wing headquarters, 1,400 to other direct support functions such as supply, civil engineering, and transportation, 500 to housekeeping functions such as food services and billeting, and 500 to the security police. It is not unusual to have 400 to 500 people on base from tenant units such as the local communications squadron, weather unit, or aerial port detachment. USAFE bases also typically have Army air defense units assigned, currently armed with Vulcan cannons and Chaparral missiles. In addition to the military community, there may be a few hundred local nationals and, on U.S. bases, numerous dependents. (The housing of a large percentage of military personnel and dependents on base, and in

many instances, in close proximity to the flightline and logistics complex is characteristic of USAF bases but not necessarily of allies.)

COMMAND AND CONTROL

The functions required of this component of an airbase include communications and information processing facilities to support decisionmaking for force employment, systems to provide detailed instructions to the operational squadrons, and systems to assure the base an adequate flow of war fighting resources. The allocation of aircraft to U.S. airbases on what is predominantly a single mission, single aircraft type basis, increases the importance of command and control by necessitating the coordinated launch of aircraft from multiple locations to mass the necessary mix of forces to effectively penetrate enemy defenses. In a MOB environment command and control can be conceptually broken into two components. On base it consists of ground lines, both point to point and multiple access, local radio nets, and wide area communication systems such as Giant Voice (loudspeakers). Between a base and other bases, including higher headquarters, facilities consist of ground lines for secure and nonsecure voice, radio communications, and digital systems, also dependent on ground lines. Functional responsibility is split between the Air Force Communication Command for on base, and the Defense Communication Agency for off base. Conversations with operational personnel readily reveal their deep concern for and dissatisfaction with command and control as it currently exists.

THE AIRCRAFT

Although it is evident that the aircraft are integral to the mission of a fighter base, it is not immediately obvious, but no less true, that the characteristics of the aircraft to a large extent determine how vulnerable the base is to the disruption of its sortie generation capability by airbase attack. A brief review of the tactics associated with airbase attacks should help explain. Recall from the previous section that during the Second World War the aircraft itself was considered the preferred target when airfields were attacked. This was true despite the inaccuracy of high-level bombing attacks and the

extreme danger inherent in having fighters drop to low level to strafe and bomb. A fundamental reason for this preference was that the takeoff and landing characteristics of the aircraft of that time were such that attacks on operating surfaces were likely to be unproductive. Fighters of that era, such as the P-47, could operate from unimproved grass strips, which were not only abundant but also easy to repair in the event they were damaged. Since that time fighters have generally become more dependent on hard, smooth surfaced runways. Their repair characteristics have also become vastly more dependent on extensive base facilities. Hard takeoff surfaces are required because of the extremely high tire pressures (in excess of 300 psi) in aircraft such as the F-15 or F-16. Smoothness is required because at high speed the current light landing gear struts would transmit loads generated by variations in a nonsmooth surface to the airframe. Modern Air Force aircraft have been designed with these intolerant undercarriages because such designs permit lighter and more compact configurations, which in turn allow for superior airborne performance. This change in aircraft technology has shifted air warfare tactics toward the denial of runways and the destruction of support structures.

Several other characteristics of modern fighters make them dependent on complex fixed bases. Dependence on such difficult to handle or to produce substances as liquid oxygen, halon, and hydrazine is one class of problem. A second type involves the large quantity of ground support equipment used by these aircraft. The end result of these characteristics is a requirement of approximately 280,000 pounds of cargo to support the deployment of a single F-16 squadron. This would require movement by about 19 scarce C-141s. Berman et al. (1985) give considerable detail concerning how such support dependence could be reduced in future fighters.

THREATS TO AIRBASES

One can readily identify seven types of threats to the continuous operation of aircraft from an airbase. These threats are:

- Unitary warhead unguided munitions;
- Ground attack by unconventional warfare forces;
- Cluster bomblets;
- Mines;
- Chemical/biological agents;
- Kinetic energy penetrators; and
- Integrated airfield attack weapons.

To better understand the potential difficulty of operating in a hostile environment, the characteristics of each of these weapon types will be discussed.

Unitary Warhead Unguided Munitions

This category of weapon can conveniently be divided into two subcategories. The first consists of common general purpose bombs, which have been around for decades, such as the Soviet FAB-250 or FAB-500. These are unguided and hence dependent on the capability of the launch platform and the skill of the pilot for accuracy. In airbase attack they have limited usefulness because they must be dropped from a dive bombing aircraft to achieve needed penetration angles for runways and hard structures such as aircraft shelters. Such an attack profile excessively exposes the attacking aircraft to base point defenses. These weapons could be used in low level attacks against soft structures such as supply warehouses or barracks.

The second type consists of weapons that have been designed specifically to penetrate runways. Ezio Bonsignore provided an excellent description of one of these weapons, the French Matra Durandal (Bonsignore, 1984):

Durandal is a 200 kg braked/boosted bomb (150 kg at impact), with a length of 270 cm, a body diameter of 22 cm, a wingspan of 43 cm and a 100 kg warhead (15 kg of this latter are represented by the HE charge); it was specifically conceived to produce very extensive damage which will take a long time to repair. The bomb is compatible with a max. carrying speed of Mach 1.8 at 10,000 m, and it is released in a low pass at high speed; minimum launching altitude is 60 m, and the speed

at release must be...between 350 and 550 knots although the version accepted by the USAF can be released at 630 knots. After release, the bomb is braked at first by a small pilot parachute and subsequently by a main one, which also stabilizes it on a 30-40 degree dive angle. A short distance above the ground a double-base propellant rocket booster is ignited, delivering a thrust of 9,000 daN [dekanewton] for about 0.45 sec. and accelerating the bomb up to 260 m/sec. in order to increase the penetration beneath the concrete runway. Matra claims that Durandal can penetrate concrete slabs up to 40 cm thick. Detonation of the 100 kg warhead, triggered by a time delay fuse (1 sec. delay), creates a crater about 5 m in diameter and 2 m in depth, and results in an important heave effect, displacing and lifting the concrete slabs for a range of about 15 m (at the edge of the crater, the slabs are raised by about 50 cm). In addition to that, repairs are made even more difficult by an outer area of heavy cracking. In total, Durandal can destroy a total runway surface of about 200-250 sq.m.

Unconventional Warfare Forces

In 1983, *International Defense Review* reported that the Soviet special warfare forces (Spetsnaz) have a peacetime strength of between 27,000 and 30,000. Although we cannot know for certain exactly what targets such units would be assigned at the outset of a war, the IDR contends that airbases are on the list. Spetsnaz are thought to operate in small teams whose purpose is to harass rather than disable a base. Tactics used might include assassination of key personnel, destruction of essential facilities such as operations centers or perhaps fuel storage tanks, and attacks on aircraft while taxiing or engaged in takeoffs or landings. Their weapons would include explosive charges, mines, small arms, mortars, rockets, and shoulder launched missiles. It is difficult to specify exactly how large a threat Spetsnaz presents to airbases; it is largely a matter of personal perceptions concerning what the Soviets intend to do with these forces coupled with a gut feel about how much risk wing commanders will accept to get their sorties launched.

Cluster Bombs

Cluster bomb units, known as CBUs, are dispenser systems that contain numerous bomblets. *Jane's Weapons Systems* described a British system used against the airfield at Port Stanley during the Falkland conflict (Foss, 1983):

BL 755 has been developed to meet a requirement for a weapon that will yield a high probability of kill against a range of small hard and soft targets....Because of the efficiency of modern surface to air systems it is operationally necessary for air-to-ground attacks...to be carried out at very low level. Any other form of attack necessitates prolonged exposure to the enemy ground defenses and negates any element of surprise. This will result in unacceptable losses to the attacking aircraft. To compensate for the aiming errors inherent in low level attack, BL 755 covers the target area with a pattern of bomblets the dimensions of which are proportional to the aiming errors. The dual function bomblets are effective against armour and soft skinned vehicles, parked aircraft, and personnel, and are distributed evenly within the pattern...147 bomblets are carried in 7 bays with seven bomblets in each bay of the bomb body...weight 277kg.

Jane's credits the Soviets with having at least seven types of CBUs. In addition it is presumed that some U.S. models fell into Russian hands in the aftermath of Vietnam. Lambeth reports that Soviet Air Force officials were noticeably impressed with Israeli use of these weapons in the Baaka Valley episode against the Syrians.

Mines

The use of delayed action weapons delivered from the air is not a new idea. What is new is the multiattribute threat presented by current mines. Older mines were either timed devices or were passive pressure devices. The newer types have active fusing systems. For example, the mines carried as part of the United Kingdom's JP 233 airfield attack system explode either when motion is detected in the vicinity or at random. Motion can be detected by both acoustic and seismic sensors. The explosion not only provides blast and fragmentation but also fires a self-forging fragment designed to penetrate aircraft and vehicle skins as well as bulldozer blades should they be used in attempts to clear the

mines. These weapons are designed not only to exact attrition on personnel and equipment but also to deny movement around a base, thus delaying recovery efforts until they can be cleared. Major Arthur Hogben, Royal Engineers (Ret.), a former commander of an EOD Squadron and the British Defence EOD School, currently the senior officer at NATO's Explosive Ordnance Disposal Technical Information Center in Kent, England, was recently quoted regarding submunitions (Daly, 1985): "One of the biggest future EOD threats is cluster munitions and submunitions. We'll defeat them - but I can't tell you how." (Necessity remains the mother of invention in modern warfare; during the Falklands conflict the British troops used sheep to clear paths through mine fields.)

Chemical Weapons

Should a war escalate to the use of chemical weapons by the Soviets, they could be delivered to airbases either by aircraft employing bombs or spray tanks or by surface-to-surface missiles such as the Scud. It is common knowledge that the Warsaw Pact trains extensively in both chemical defense and offense. Numerous reports have surfaced in the West concerning use of chemical agents by the Soviets or their clients in Southeast Asia, the Middle East, and Afghanistan. The goal of chemical attack on an airbase would be more to slow down sortie production or base recovery by forcing base personnel to work in hot, cumbersome, chemical protective suits than to kill people.

Kinetic Energy Penetrators

The boosted kinetic energy penetrator (BKEP) is a good example of this developing type of ordnance. Again Bonsignore (Bonsignore, 1984):

The BKEP is a dual purpose (runway cratering/anti shelter) braked/accelerated munition. It is released by its carrier (sideways) from low level horizontal (or shallow dive) flight; upon ejection, four semicircular fins deploy and stabilize the sub-munition. Deployment of a small pilot parachute causes ejection of the main chute; this latter brakes the BKEP retarding its forward motion, and inclines the submunition to 65 degrees from the horizontal. The rocket motor ignites at the programmed time causing the main chute to jettison and accelerating the BKEP to the required velocity....Dimensional data released so far about BKEP is that its total weight is 19.5 kg of which 3 kg is the H.E. charge.

A submunition, like cluster bomblets and mines, BKEP is designed to be an area weapon thus eliminating the need to expose attacking aircraft while they select aim points and make precise run-ins on their targets. The theory on small size is that many small craters are more difficult to repair than a few large ones.

Integrated Airfield Attack Weapon Systems

This type of weapon was devised to present an opponent with several difficult problems simultaneously in the wake of a limited number of low-level attack sorties. Mark Hewish describes JP 233 (Hewish, 1984):

Each weapon system comprises two complementary disposable airborne dispensers, one housing 30 cratering submunitions and the other accommodating 215 area-denial mines. Tornado will carry two such weapons (i.e., four dispensers), and will dispense its complete load of submunitions and mines in a single pass across or along the target runway or other operating surface. This produces a line of craters completely overlaid by a high density minefield that is effective against aircraft, vehicles and personnel....The incorporation of an area-denial mine in the weapon system substantially extends the period for which an enemy airbase is closed, however, and the mine-clearance time becomes the dominant factor.

A typical release of JP 233 would occur at 500 kt and 200 ft. The cratering submunition (SG357) pod weighs 1,370 kg; the mine (HB876) dispenser 1,150 kg.

The Luftwaffe has a similar system known as the MW-1. This system can be used for both antiarmour and airfield interdiction. In the airfield attack role MW-1 carries either STABO (Startbahnbombe) runway cratering munitions or a mix of mines: MUSPA (Multi Splitter Pasiv/Aktiv), MUSA (Multi Splitter Aktiv), and MIFF (Multi Flach-Flach) mines. MUSPA is acoustically and randomly triggered; MUSA is more like a CBU than a mine in that it detonates shortly after hitting the ground, destroying aircraft and vehicles caught in the open; and MIFF is an antiarmor device included to prevent rapid clearance of the minefield. System weight is approximately 4.5 tons.

There have been no reports in the open literature of the Soviets' developing this type of capability. Policymakers must judge whether it is reasonable to assume that the Soviets are technically capable of producing such weapons or are likely to do so.

RECOVERY AFTER BASE ATTACK

The process of recovering after a successful attack is a very complex operation. Immediate crises such as fires and wounded personnel must be dealt with at the same time as the command section is attempting to ascertain the extent of the damage. The first order of business is usually to return takeoff and landing surfaces to some minimum criteria expressed as a minimum clear length and minimum clear width. The selection of this Minimum Operating Surface (MOS), unless immediately obvious because of minimal runway damage, must await inspection by survey teams, which themselves may be delayed by mines or other unexploded ordnance. Following selection of the MOS, the immediate area and its approaches must be made safe by Explosive Ordnance Disposal (EOD) teams for the large number of personnel and equipment required to repair craters.

Crater repair is not merely the simple filling in of a hole and topping it off with some sort of quick-setting substance. A crater can be very impressive and its repair may consume considerable resources, especially when crews engage in the highly coordinated efforts necessary to make repairs quickly. Furthermore, there is more than one type of crater. Obviously size is relevant, one school of thought maintaining that many small craters are more difficult to repair than a few large ones. Next there is the behavior of the ejecta. Was it blasted clear or did much of it fall back into the crater requiring time-consuming excavation as part of the repair? Worst of all, is it a camoflet, i.e., a crater having little more visible than an entry hole but possessing a void of unspecified diameter and depth ready to cave in under heavy equipment that ventures too close? Crater repair technology continues to change as the civil engineering community struggles to devise a procedure that will satisfy the need for speed in repair in the face of the unforgiving nature of current fighter landing gear. Table

3.1 should give a reasonable idea of what is involved in the repair of a single crater 14 m in repair diameter using precast concrete slabs, one of the currently competitive procedures (Bergholz and Flint, 1983).

USAF RESPONSES TO AIRFIELD ATTACK THREATS

The U.S. Air Force has taken numerous actions to temper the threat to airbases:

- Main operating bases have been provided with hardened aircraft shelters. NATO infrastructure funds shelters for 70 percent of assigned aircraft. (That is, the money is provided through the NATO budget rather than from national sources.)
- Wing and Squadron Operations Centers on MOBs have been hardened, also under the infrastructure program.
- Agreements have been reached permitting USAF squadrons to operate at allied bases (known as Collocated Operating Bases--COBs). The COBs are also eligible for NATO funding of shelters and operations centers. This program permits the

Table 3.1

RESOURCES REQUIRED FOR CRATER REPAIR

10 men
1 ten-ton tractor
1 22-ton semi-trailer
1 farm tractor
4 front-end loaders
1 towed rotary sweeper
3 ten-ton dump trucks
2 concrete breaker/excavators
2 concrete cutting saws
1 screed beam
1 1500-gallon water truck
1 tool trailer
150 cubic meters of railroad ballast (60 mm)
50 cubic meters of gravel (10 mm)
49 precast concrete slabs (2 m x 2 m x 0.145 m)
2 cubic meters of sand

dispersal of U.S. augmentation forces so that USAFE MOBs are not overloaded. Since the COBs are MOBs of Allied Air Forces they have limited impact on the uncertainty problem. The program makes these bases relatively more lucrative targets but simultaneously reduces the value of the U.S. MOBs where they would otherwise be deployed to.

- MOBs have been hardened at U.S. expense beyond that contributed by NATO. Numerous soft buildings have been surrounded with blast walls. Deception programs have been initiated using such techniques as tone down paint schemes and camouflage netting.
- Active defenses have been enhanced. Patriot is replacing Nike, and Stinger is replacing Redeye. Also, Rapier has been purchased from the British under an agreement that calls for the RAF regiment to man the system. However, recently the DIVAD radar controlled gun system was cancelled. Finally, the combination of AWACS and the newer fighters improves air-to-air capabilities significantly.
- The USAF has chartered a program office with the responsibility of developing and integrating approaches to insure base survivability.

Despite these actions the possibility remains that USAF responses to these threats will not permit the sustained operation of sortie generation activities in the event the enemy is successful in degrading MOB operations for extended periods of time. This is largely because current aircraft are wedded to MOBs.

THE MOB/DOL CONCEPT

Dispersal can be defined in a number of different ways: One (the Harrier) concept would remove all aircraft from the peacetime MOB; another would scatter aircraft around the perimeter of the MOB. The dispersal examined here involves the removal of 32 of the wing's 72 aircraft from the MOB. These 32 would be divided into four groups of eight; each group would occupy one of ten possible sites available to each MOB.

Each DOL site would have a 3,000 to 3,500 ft runway and approximately 12 parking pads spaced at least 300 ft apart. POL would be supplied by truck operating from Central European Pipeline System (CEPS) refueling points. Munitions would be trucked from storage points such as U.S. Army Ammunition Supply Points. Billeting and messing could be handled with appropriate field gear or if possible with local area facilities. (Materiel and personnel requirements and costs are covered in more detail by Berman et al. (1985).)

Security police could be augmented by arming maintenance and other support personnel. This is the concept used at air launched cruise missile (ALCM) bases; a total of 69 men defend the 16 nuclear armed missiles of each ALCM flight. Security would be further enhanced by moving the sites each 48 to 72 hours.

Command and control should take advantage of new developments in the burst transmission of data as appropriate; backup would include radio and commercial ground systems. Examination of command and control for existing analogous systems, such as ALCM, Harrier (RAF and USMC), and Army helicopter units, might yield viable alternatives.

This concept envisions DOLs as complementary to MOBs rather than as replacements for them. The MOBs remain as integral parts of this basing scheme for several reasons. First the MOB is likely to remain a hard target requiring numerous sorties to close even for a short time. Next, the maintenance concept of operations would return aircraft with significant maintenance problems or battle damage to the MOB where the extensive facilities and large pool of personnel could better handle repairs. Finally, looking to the longer-run consequences, the presence of the two types of operating locations would give the Soviets more difficult choices to make in the development of their combat systems. The decision to disperse would be a tactical matter to be decided on in view of the threat as it exists at the time of conflict. Dispersal preserves tactical flexibility for unit or theater commanders rather than prescribing choices through doctrinal or hardware rigidity. Aircraft with the characteristics desirable for dispersal would also enhance strategic flexibility, since they could operate more readily in regions where MOBs do not exist.

IV. RISK AND UNCERTAINTY

But what kind of assumptions do we tend to make? How do these assumptions channel our thinking? What alternative perspectives are available?

Graham Allison

INTRODUCTION

This section provides some background in the area of risk and uncertainty analysis, most of which has been developed in the areas of health and safety. It will outline the sources of uncertainty, some alternative methods available to analysts, and the methodology used in the study.

One approach used to examine aircraft basing alternatives has been to assume some fixed probability of an attack on the base and then to measure the performance of aircraft by type of basing against a specified scenario using analytic or simulation models. Typically, the probabilities of attack have been set at 1.0 for MOBs and at either 1.0 or 0.0 for DOLs. The treatment of uncertainty is therefore reduced to parameterization of attacking aircraft force levels and attrition rates. However, if a conflict were to break out in Europe in the near future, it would not be implausible for a commander to believe that not all his MOBs would be attacked. Similarly he might justifiably believe that some dispersed sites, were he to have any, would not escape enemy assaults. Expected value and extreme point estimates can mask valuable information about risk. Thus distribution of possible outcomes would be more valuable to a commander than would the extreme point or points that can be provided by parameterization type studies. Emerson gets to the heart of the difficulty that parameterization analysis leaves leadership with (Emerson, 1969):

Today's decisionmaker is keenly aware that there are significant uncertainties about the future threat and about the performance characteristics of future weapons systems. To aid him in arriving at his decisions, the impact of the uncertainties that surround an issue are examined regularly with parametric studies

and sensitivity studies. Unfortunately, such analyses become increasingly ponderous and difficult to interpret as the model employed becomes more complex, and as the number of uncertain factors increases. Customarily such studies consider the uncertainty in only one factor at a time; they do not normally attempt to estimate the joint influence of several uncertainties. Furthermore, such studies implicitly consider the uncertainties to be transitory, since they are not assumed to affect battle planning. And there is no mechanism in such studies for the systematic introduction of a spectrum of expert opinion regarding our degree of uncertainty.

Consideration of alternative basing policies in the face of a hostile force is clearly fraught with numerous instances of uncertainty. The consequences of several uncertainties are difficult to perceive in terms of aircraft or sortie losses when each uncertain parameter is varied individually. This analysis aims at performing that needed integration.

TYPES OF UNCERTAINTY

Four basic sources of uncertainty have been identified by Bolten et al. (1983):

- *True stochastic characteristics of some element of the problem.* An example of the presence of this source of uncertainty in this study is the inherent variability in the free fall characteristics of gravity weapons. Even if a weapon is released within parameters, and at the appropriate point in space and time, and at the proper speed and angle, there still remains an unpredictable element, known as ballistic dispersion, which causes the weapon to be, on average, off target.
- *Lack of sufficient knowledge of the correct values for input parameters used.* This study attempts to decompose the base attack problem by treating detection of DOL operations, penetration to the target, and weapons release as independent probabilities. None of these crucial probabilities is known with any precision.

- *Variations among alternative models that could be used.* Inputs to this study are sometimes derived from other models; for example, the damage estimates can come from the TSARINA simulation (Emerson and Wegner, 1985), or from interview techniques. Neither technique is verifiable in any definitive sense because of the impracticality of conducting experiments on any large scale.
- *Potential lack of completeness in the overall analysis.* Often an analysis is forced into this type of uncertainty by the need to bound the problem. Such is the case in this study; variations in Defensive Counter Air results are not considered, although clearly a highly capable defensive system would obviate the need for tactical dispersal.

The crux of of this analysis, then, is to examine the extent to which uncertainty in the input parameters can affect the outcome. This is known as uncertainty propagation analysis.

ALTERNATIVE THEORETICAL APPROACHES

Bolten et al. identify theoretical approaches to the quantification of uncertainties associated with input and parameter values. The advantages and disadvantages of each are outlined in Table 4.1, which has been extracted from that study. That report is also the basis for the following discussion of each method.

Analytic Approach

The analytic approach is applicable only when an explicit formula, equation, or system of equations that can describe an output function in terms of all inputs is available in a mathematically tractable form. A danger here is the temptation to make assumptions necessary to fit the mathematical techniques available without a complete appreciation of the impact of those assumptions on the outputs. This method is very advantageous for simple problems, and its ability to rank inputs in order of importance is desirable. However, as problems become more complex the technique becomes more difficult to implement and explain to decisionmakers.

Table 4.1

ADVANTAGES AND DISADVANTAGES OF UNCERTAINTY ANALYSIS METHODS

Method	Advantages	Disadvantages
Analytic	Ranks uncertainty contributors Precise	Limited application Expensive May be too complex
Monte Carlo	Widely applicable Easy to develop confidence intervals	Sensitive to input assumptions Cannot rank uncertainty contributors Long computation times May be too complex
Response surfaces	Economical Widely applicable Ranks uncertainty contributors	Hard to assess accuracy
Differential sensitivity	Widely applicable Accurate Ranks uncertainty contributors	May be difficult to compute
Confidence intervals	Measures uncertainty caused by statistical variability in data	Not always applicable Cannot rank uncertainty contributors
Extreme value	Gives range of uncertainty Economical	Point information Range too broad
Linear propagation	Accurate Applied in modularized fashion	Must model process Difficult to estimate component uncertainty
Simple sensitivity	Simple Inexpensive	Cannot bound uncertainty

Monte Carlo Simulation

In the Monte Carlo approach the output function is simulated directly by assigning to each of the input functions a set of joint probabilities. One takes a large number of independent samples from these distributions forming the joint

probability--and calculates the corresponding outputs. The laws of probability assure that as sample size increases, this spectrum of outputs provides a good representation of the true output distribution.

(Bolten et al., 1983)

This means that there is no constraint on the system description imposed as a result of issues of mathematical tractability. Law and Kelton find this property extremely important (Law and Kelton, 1982): "Most complex, real world systems with stochastic elements cannot be accurately described by a mathematical model which can be evaluated analytically. Thus, a simulation is often the only type of investigation possible." They also identify another significant advantage in the context of this study, that is, the ability of simulation methodology to compare alternative system designs. On the negative side, Monte Carlo simulations can require a large number of runs, and these runs can be expensive in terms of time and money. Next, the impact of changes in a single input parameter is difficult to quantify; ranking of contribution is not possible.

Response Surface Approach

To overcome the disadvantages of the Monte Carlo approach, the output function of a Monte Carlo is replaced by an analytic approximation which is termed a response surface. Often the approximation is made by assuming that the output function is a linear combination of simpler functions the coefficients of which are computed using least squares. This technique is economical; however, it is difficult to determine how accurately the response surface fits the original output function.

Differential Sensitivity Approach

This approach involves setting up and solving a set of linear equations obtained by differentiating the general output function. These sensitivity functions are then combined with measures of actual input uncertainty to obtain output uncertainty estimates. This direct linking of input to output in the development of the sensitivity

equations is desirable; however, in complex problems the task of solving the equations to set up the sensitivity functions may take a considerable amount of time. Also, computation time may become a problem if it is necessary to evaluate several sets of input parameters to accommodate large variations in those inputs.

Confidence Interval Approach

Where the system is well defined analytically and sufficient data are available to estimate input parameters this statistical confidence bound approach is appropriate. It provides estimates of output uncertainty based only on variability of input.

Extreme Value Approach

Minimum, best, and most likely values of each primary input parameter, and appropriate combinations of them, are used to generate a best, pessimistic, and optimistic estimate of system performance. Thus the approach gives a broad range of estimates but no sense of distribution.

Linear Propagation of Errors

This approach is based on a first-order Taylor series expansion of the calculated quantity in terms of random input parameters and permits the calculation of variance from the sensitivity coefficients and covariance structure of the input parameters. It may be applied in a modularized fashion and is therefore useful in multisystem risk calculations. Its applicability is limited by the extent to which the uncertainties in transport and other models can be bounded.

Simple Sensitivity Analysis

In this approach inputs are rank-ordered based on sensitivity of the output to the parameter. A "reasonable" range of variation in the inputs is then examined individually and in pairs. The approach does not bound the final output but it does distinguish between sensitive and insensitive data, tending to approximate the bound.

APPROACH USED IN THIS STUDY

The analytic technique chosen for this study is an adaptation of Emerson's Theater Air-Ground Simulation (TAGS) model, which has attributes of both a deterministic analytic model and a Monte Carlo simulation. The model has been modified to incorporate the uncertainties regarding the detection of, penetration to, and the delivery of weapons on airbases. TAGS was chosen as the vehicle for conducting this analysis because of its ability to deal with uncertainty explicitly. It is a highly aggregated probabilistic simulation model in which ground and air activities are assessed day to day. Figure 4.1 provides a schematic representation of the forces and types of operations included in the model. TAGS handles uncertainty through a feature that permits most model parameters (see the Appendix for a list of input parameters) to be specified as having uncertain values. Each simulation trial uses sample values from specified probability distributions (Fig. 4.2) for each factor declared uncertain. Thus the results include a statistical summary of the joint influence of several uncertain factors.

Five criteria have been outlined upon which to base appropriateness of a model for use in risk assessment (Bolten et al., 1985):

- Sound mathematical basis;
- Applicability to the current problem;
- Ease of application;
- Acceptability; and
- Testing/verification.

TAGS meets these criteria reasonably well. Simulation is a technically acceptable methodology as well as a technique that many decisionmakers are familiar and comfortable with. For example, within the Air Force, the direct labor component of maintenance manpower requirements is largely determined through use of a simulation model known as the Logistics Composite Model (LCOM). Maintenance is the largest single consumer of enlisted manpower in the Air Force. The incorporation of uncertainty makes it especially applicable in this work, and the methods

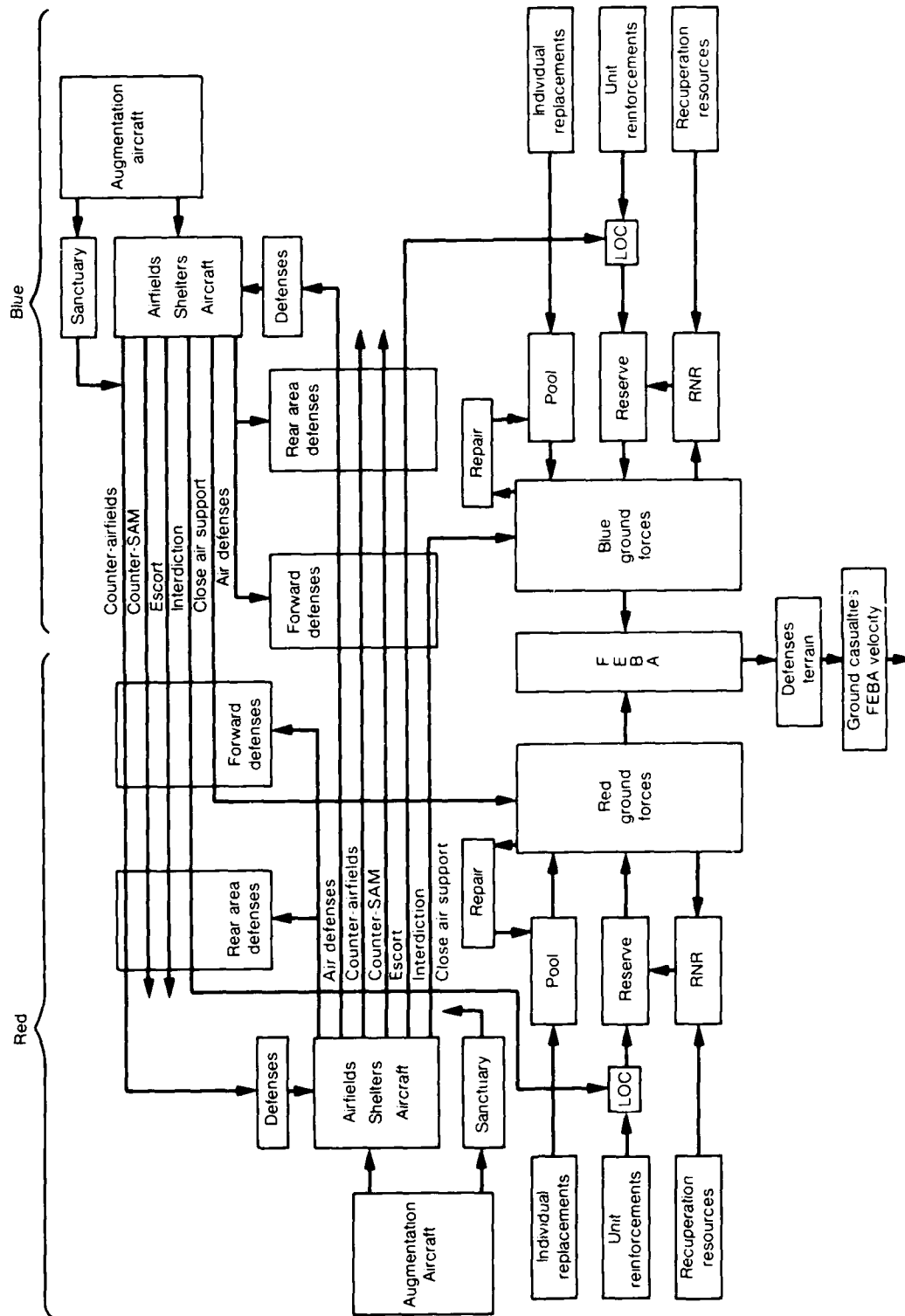


Fig. 4.1—Interactions in TAGS

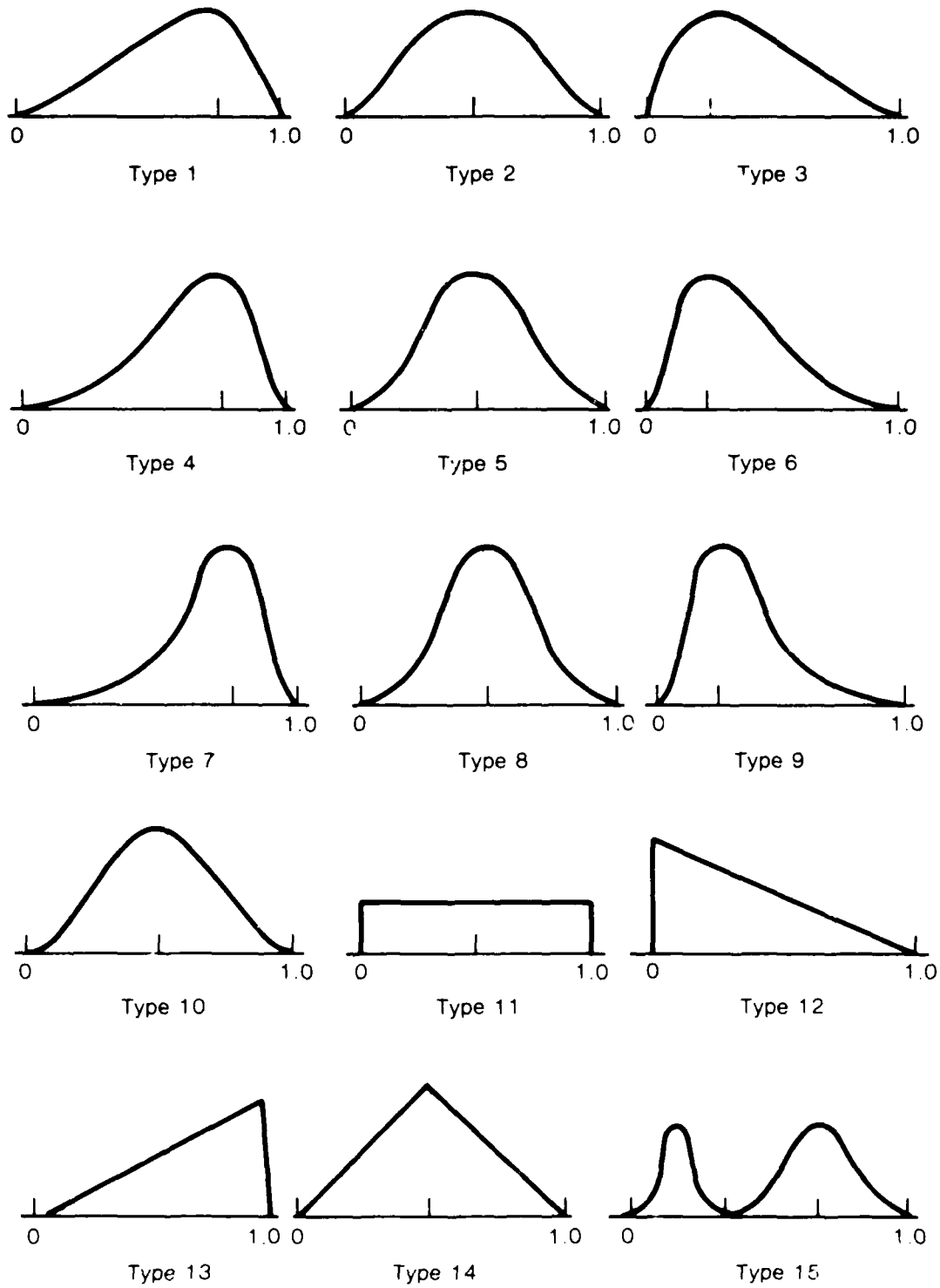


Fig. 4.2—Distributions available in TAGS

used to code and provide inputs to the model make it easy to use. Complete testing and verification of outputs, as with any combat model, is not possible; however, with some experimentation the features addressed by the modifications could be examined.

THE MODIFICATION

To attack an enemy airbase, a number of activities must be accomplished. Some of these are fundamentally under the control of the attacker, such as the preparation of aircraft and aircrews; others are beyond his ability to influence, such as weather and enemy defensive capabilities. The concept of dispersed operating locations is attractive because it adds or at least increases the difficulty of two tasks:

Detection--Can enemy intelligence locate dispersal sites and determine whether they are operational soon enough to permit an attack before the DOL assets are redeployed? The Warsaw Pact might use any number of sources to detect the sites: Spetsnaz, space-based sensors, native agents, photo reconnaissance, and so forth; however, both the sources and the assets used to process their output are limited. Opinions can vary significantly regarding their ability to detect small unit operations and process the information in an operationally meaningful timeframe.

Penetration/Navigation--NATO has in place both a Hawk missile belt (soon to be upgraded to Patriots) and a significant number of air defense aircraft with which to disrupt an attacking force. Terminal defenses such as Vulcan guns and Chaparral Short Range Air Defense (SHORAD) missiles can prevent delivery, destroy pilot concentration necessary for accurate delivery, or preclude subsequent attack sorties. Finally, navigation at low level to an unfamiliar location (one presumably employing an active deception program), under the stress of initial combat sorties, probably hampered by poor weather, is not to be taken for granted. For example, in West Germany, 29 percent of which is covered in wood and forest, an average of one-third of autumn and winter mornings are foggy for five to six hours with visibility limited to less than 1 km. In addition, ceilings below 2,000 ft exist from 16 percent

of the time during summer months to 43 percent in the winter. Although the penetration and navigation tasks are also necessary to attack MOBs, DOLs would probably be more difficult targets because of their small size and less built up nature.

The TAGS model has been modified to accommodate the uncertainties of detection and penetration/navigation as well as the likelihood that some proportion of arriving attackers will choose an inappropriate aimpoint for weapons release. TAGS inputs can be structured to deal with aircraft protection levels ranging from completely unsheltered, through conventional sheltering, or even to aircraft in sanctuaries. It does not deal specifically with runway cutting or with the other disruptions associated with airbase attack; these consequences must be dealt with through parameterization of sortie generation rates. The model's high computational speed, ease of use, and ability to accept uncertainty make it an especially appropriate tool for exploratory work such as this.

V. ANALYSIS

But we must ourselves take care not to acquire a Maginot dependence upon ground based static systems and infrastructure.

Sir Keith Williamson
Air Chief Marshal
Chief of the Air Staff
United Kingdom

SCENARIO

The scenario examined in this Note involves the first five days of a conflict in which the enemy conducts a campaign against airbases resulting in attacks being delivered on days one, two, and three. The size of the initial attacking force is parameterized at one and two regiments of 36 aircraft each against each 72 PAA USAF Wing. The enemy is assumed to have sufficient fillers to begin each day's attacks with full regiments. Attacks are targeted against aircraft on the ground because of limitations of the TAGS model; however, runway interdiction is explored by examining the effect of uncertain sortie rates that such attacks could cause. In the absence of any attacks the five wings of aircraft are assumed to be able to produce:

$$360 \text{ aircraft} \times 3.0 \text{ sorties/day} \times 5 \text{ days} = 5,400 \text{ sorties}$$

For the cases where the enemy has only 36 aircraft to send against each wing, he generally chooses to go against the DOLs; the single exception occurs in the excursion where his attacks are assumed to degrade sortie rates. When he has 72 aircraft available to attack each wing, he devotes half the force to DOLs and half to MOBs.¹

¹Sensitivity analysis showed small relative change in results by measurable variations in this ratio.

PARAMETERS

The values and distributions used in TAGS are shown in Table 5.1. Also, the decision logic present in airbase attacks is presented in simplified form in the probability tree diagram of Fig. 5.1. This diagram highlights the probabilistic nature of such an attack. This formulation of the problem requires estimates that are not commonly made, such as the likelihood that a DOL would be detected. Such estimates could be empirically made after experimentation; however, such experiments have not been conducted. Therefore, techniques of probability elicitation were used whereby subjects were asked to give subjective assessments of the parameter values and range of uncertainty involved in their estimation of each of the relevant probabilities. The values arrived at and the distributions inferred are not presented as scientifically valid conclusions but rather as first approximations with which to examine the role of uncertainty in examining alternative basing modes. Indeed, wide variations in opinion surfaced among those interviewed, despite their similar backgrounds and high degree of interest in the area.

Table 5.1
VALUES AND DISTRIBUTIONS USED IN TAGS

Parameter	Most Likely Value	Range	Distribution Type
DOL detection	0.8	0.9	15
DOL penetration	0.6	0.8	7
DOL aim point selection	0.6	0.5	4
MOB penetration	0.7	0.6	4
MOB aim point selection	0.7	0.4	7

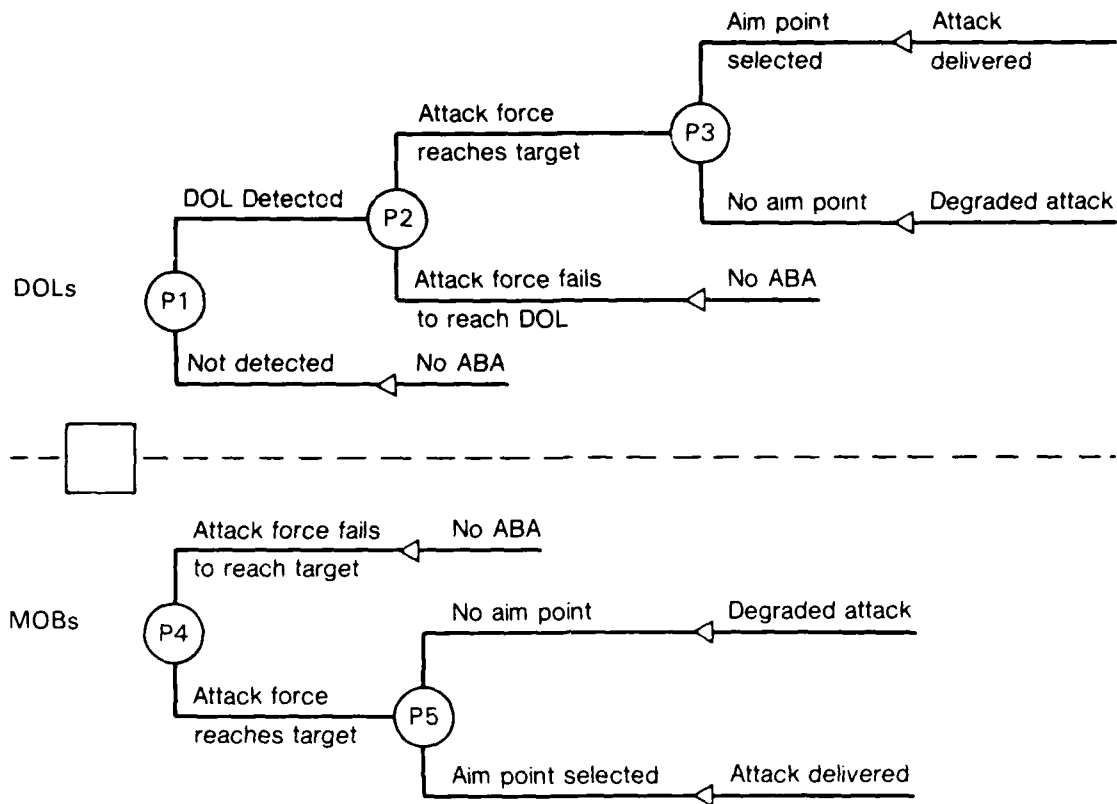


Fig. 5.1—Airbase attack probability tree

Other inputs of special interest include a fixed sortie rate of 3.0 per day for all blue aircraft unless noted otherwise and an attack effectiveness against aircraft approximated by the formula:

$$A = A_o (1 - P)^S$$

where:

- A = remaining aircraft on base
- A₀ = aircraft on base before the attack
- S = attacking sorties
- P = selected so that aircraft in revetments have about one-third and sheltered aircraft one-hundredth the vulnerability of those parked in the open

Finally the proportion of aircraft on base during attacks was set at 0.2 for DOLs (range 0.5, distribution 9), and 0.7 for MOBs (range 0.9, distribution 15). This implies a considerable capability for DOL aircraft to escape. For the MOB it infers a situation in which some assets always escape and occasionally almost all aircraft are gone at the time of the attack.

QUANTITATIVE MEASURES OF MERIT

Two quantitative measures available as outputs from TAGS help us understand the costs and benefits of each basing mode. Sorties generated in the first five days of conflict is the first measure. Its utility is fairly obvious; airpower is of little use to a commander if it is largely earthbound by loss of operating surfaces or of limited effectiveness because many aircraft are destroyed on the ground. One can only speculate regarding just how important airpower will be early in a conflict; however, the words of Air Marshall Sir Patrick Hine, for two years Commander Second Allied Tactical Air Force (2ATAF) and Commander-in-Chief of Royal Air Force Germany, lend some urgency to early sorties:

I believe very strongly that, if war should ever break out in the Central Region, we must seek to give the Warsaw Pact early on what I call a bloody nose. The great majority of their aircrew would have no experience of war, they would be flying over strange terrain which was demonstrably unfriendly, and they would be trying to fly much lower than they normally train in peacetime; so the enemy would have a difficult task.

If we could, by using our air defenses in the right way and by getting as many fighter aircraft as possible airborne to break up his early mass raids, cause him to evade hard and

jettison his weapons, frustrate his attacks, and inflict high attrition on him, then we may begin at the end of the first one or two days to gain the psychological upper hand.

We could not, however, gain a favorable air situation by remaining on the defensive alone. We would have to take him by the throat and, as soon as we got political clearance, pin him down on his airfields through our own offensive counter air attacks. Only that way, with the right combination of offensive and defensive operations, could we begin to wrest the air initiative from the enemy.

The second quantitative measure, aircraft lost to airbase attack, is by no means independent of the first. Dead aircraft do not produce sorties; airborne assets cannot be killed on the ground. However aircraft lost, or its complement, aircraft remaining measure residual combat capacity. It is an "inventory remaining" view, whereas sorties flown is more in the nature of a flow. It is a measure that is perhaps especially important to the United States in view of our numerical inferiority to Soviet forces. Aircraft remaining is not obviously sufficient in itself as a measure of basing effectiveness; e.g., Arab air forces had lost few assets by the end of the 1973 conflict largely as a result of an effective hardening program, however Israeli attacks were able to prevent the generation of sorties.

The notion here is that these two measures are traded off, one against the other. More sorties early in a conflict are likely to cost more in terms of aircraft killed on the ground. It is a difficult but crucial decision to decide where the balance point is. When is it so important to deliver attacks or to defend from the air that the risk of having aircraft exposed on the ground is acceptable?

QUALITATIVE MEASURES OF MERIT

All too often analysis of aircraft vulnerability on the ground is reduced to simple force exchange calculations--a bean counting exercise. Lambeth expressed such concern well in a recent paper (Lambeth, 1985):

Although we routinely talk about our requirements as a function of the "threat," all too often the assessments that go into tactical force planning look solely to the technical aspects and size of the enemy's forces, without much thought given to consideration of context or to those important

intangibles relating to the enemy's operational prowess that will govern how--and with what effect--his technical assets might perform in combat. We need to assess enemy capabilities not just in terms of hardware but from an operational perspective. For one thing, that is the context in which we will fight the Soviets should war come. More important, assessments of enemy capability divorced from an operational setting tend to produce misleading images....Fixation on force size as the most important ingredient of enemy capability is a classic case of bookkeeping masquerading as analysis. It overlooks the dynamic elements of war.

It is in this spirit that these nonquantitative issues are raised.

An advantage of dispersal hinges on Sun Tzu's description of a skilled general, "His primary target is the mind of the opposing commander." Delivery of an attack on a DOL involves yet a fourth uncertainty--whether or not, given DOLs have been detected, the enemy will choose to target them. For several reasons he might choose not to do so. First, efficient use of forces would require that he fragment his regiments to approximately squadron size, thus violating what is commonly felt as a bias toward large unit actions and close held control. Second, he would have no assurance that anything of value would be at the target by the time a force could be dispatched. This is in marked contrast to MOB attacks where he is assured of finding at least a valuable infrastructure to punish. Third, there is the question of whether DOLs would rank high on his list of target priorities even if he had complete faith in his intelligence system and harbored no qualms about small force sizes. This analysis conservatively assumes that he always chooses to target the DOLs when they are detected.

From the Soviet point of view it is desirable to make USAF forces predictable. DOLs lessen this predictability in three ways. At initiation of a conflict in Central Europe they would serve to introduce doubt in a Warsaw Pact commanders mind as to whether he could suppress NATO airpower for even a short period of time. It would do this by making base closure more difficult. Without complete surprise, catching all NATO assets on their home MOBs, he could have no assurance of exactly how many aircraft, and of which type, he could successfully suppress during critical time periods. Similarly, in other theaters where the Soviet government might be tempted to use military power,

either its own or that of allied states, the ability to operate from small, austere strips could serve to place U.S. airpower into his calculus where previously it was not a concern because of its dependence on large, fixed base structures. Finally, in the longer run, the more complex target set presented by a MOB/DOL basing structure imposes a more difficult task on his weapons development community than the runway/shelter busting required by MOBs alone.

RESULTS

Certainty

This first series of results, which are characterized as "certainty" for convenience more than accuracy, reflect the outcomes of the attacks under the assumption that the enemy knows where all 360 USAF aircraft are, penetrates and navigates successfully to each location, and drops his weapons with the prescribed accuracy in every case--the ten foot tall Russian, if you please. Table 5.2 presents the results of this series of runs. As with each of the following tables for each basing configuration, the first line presents sorties followed by the standard deviation in sorties where appropriate. The second line gives aircraft killed and its standard deviation. For the one regiment

Table 5.2

EFFECTS OF "CERTAINTY" ON SORTIES AND AIRCRAFT LOST

Basing	Attack Size	
	One Regiment	Two Regiments
MOB	5030 46	4700 sorties 85 losses
MOB/DOL Aircraft in open	4640 79	4510 sorties 95 losses
MOB/DOL Revetments	4910 55	4780 sorties 71 losses

attack, the results indicate a clear superiority in MOB performance; 93 percent of the 5,400 theoretical maximum sorties are flown compared to 86 percent and 91 percent for the open and reveted DOLs, respectively. The aircraft lost measure ranges from 13 percent lost at the MOB to 22 percent at the unprotected DOL. The intensity of the two regiment attacks gives the reveted DOL structure an advantage; aircraft losses are reduced (20 percent compared to 24 percent), but the benefit to sorties produced is only slight (89 percent compared to 87 percent). This is a conventional method of analyzing dispersal: Outcomes are based on critical assumptions, such as the number of aircraft remaining on base during an attack and the number of DOLs attacked.

Risk Only

These runs treat the most likely estimates as expected values; no distributions are specified that would reflect uncertainty in the estimates. Each outcome tends to reflect a diminished capability of the enemy to attack each site where USAF aircraft are located relative to the certainty case. This consideration of risk tends to reverse the relationship between basing types; the MOB/DOL combination looks

Table 5.3
EFFECTS OF RISK ON SORTIES AND
AIRCRAFT LOST

Basing	Attack Size	
	One Regiment	Two Regiments
MOB	5110 35	4890 sorties 62 losses
MOB/DOL Aircraft in open	5180 27	5090 sorties 38 losses
MOB/DOL Revetments	5260 17	5170 sorties 29 losses

somewhat superior at both threat levels. The MOB produces between 91 percent and 95 percent of its sorties and loses 10 percent or 17 percent of its aircraft. The MOB/DOL (Unsheltered) configuration produces 96 percent and 94 percent of its sorties, while losing 8 percent and 11 percent of its aircraft. The MOB/DOL (Reveted) configuration keeps sorties at 97 percent and 98 percent with aircraft losses of 5 percent and 8 percent.

Uncertainty

Table 5.4 gives the results for the runs that include the complete treatment of uncertainty. Detection, penetration, weapons delivery, and number of aircraft on base at the time of the attack are all represented by probability distributions. The MOB/DOL configuration continues to appear superior; however, the situation is much less certain when the variance involved is considered. A commander gets only one trial, not 200. It seems plausible that one could judge these outcomes as roughly equivalent, especially so if one is more sanguine about the level of protection provided by shelters on MOB's.

Table 5.4
EFFECTS OF UNCERTAINTY ON SORTIES AND AIRCRAFT LOST

Basing	Attack Size	
	One Regiment	Two Regiments
MOB	5300/16 12/2.6	5220/46 sorties/std dev 23/5.9 losses/std dev
MOB/DOL	5330/36	5300/49 sorties/std dev
Aircraft in open	9/4.4	13/5.7 losses/std dev
MOB/DOL	5350/20	5320/33 sorties/std dev
Revetments	6/2.4	10/3.7 losses/std dev

Fraction of Aircraft on Base Uncertainty

Tables 5.5 through 5.7 add uncertainties, one by one, to the basic risk only case. The purpose of this procedure is to gain an appreciation of the relative importance of each added uncertainty. The first set of runs strips away the risk relative to detection, penetration, and weapons delivery, leaving uncertain only the number of aircraft remaining on base during an attack. They serve to illustrate the criticality of the combined effect of detection, penetration, and weapons delivery on the DOL outcomes. The MOB basing posture is affected to a much smaller degree than either of the MOB/DOL options. The MOB averages 96 percent of its sorties while losing 7 percent of its aircraft. The unprotected MOB/DOL configuration produces 89 percent of its sorties and loses 19 percent of its aircraft. The reveted structure maintains 92 percent on sorties and loses 14 percent of fighters.

Table 5.5

EFFECTS OF UNCERTAINTY ON SORTIES AND AIRCRAFT LOST
(FRACTION REMAINING ON BASE UNCERTAIN)

Basing	Attack Size	
	One Regiment	Two Regiments
MOB	5260/24.0 18/3.6	5140/62.2 sorties/std dev 32/7.5 losses/std dev
MOB/DOL	4820/112	4780/126 sorties/std dev
Aircraft in open	65/10.7	71/12.4 losses/std dev
MOB/DOL	4990/54.6	4950/69.2 sorties/std dev
Revetments	48/5.8	54/7.5 losses/std dev

Weapons Delivery and Fraction of Aircraft Remaining Uncertainty

Now we add the uncertainty about to the ability of attacking pilots to identify a valid aim point and to execute an attack. Results, shown in Table 5.6, show a fairly uniform 2 percent to 3 percent increase in sorties across the board. Losses on MOBs are reduced by 3 percent and on the DOLs by 4 percent.

Fraction Remaining, Weapons, Penetration Uncertainty

In Table 5.7, uncertainty about the ability of the enemy to penetrate defenses and to navigate to the target areas is added. The addition of penetration has little effect on the MOB performance, but it increases sorties for the other two options by approximately 4 percent, and it reduces losses by between 3 percent and 6 percent.

Bear in mind that each of these parameters can be influenced by the defender through active and passive defense, deception, and tactical alternatives. Other chance happenings, such as poor weather or equipment malfunctions, can also have a significant impact.

Table 5.6

EFFECTS OF UNCERTAINTY ON SORTIES AND AIRCRAFT LOST
(FRACTION REMAINING AND WEAPONS DELIVERY UNCERTAIN)

Basing	Attack Size	
	One Regiment	Two Regiments
MOB	5310/21 12/3.0	5220/44 sorties/std dev 23/5.8 losses/std dev
MOB/DOL	4950/68	4920/80 sorties/std dev
Aircraft in open	52/6.9	56/8.2 losses/std dev
MOB/DOL	5120/57	5090/69 sorties/std dev
Revetments	33/6.1	38/7.4 losses/std dev

Table 5.7

EFFECTS OF UNCERTAINTY ON SORTIES AND AIRCRAFT LOST
(FRACTION REMAINING, WEAPONS, PENETRATION UNCERTAIN)

Basing	Attack Size	
	One Regiment	Two Regiments
MOB	5300/16 12/2.6	5220/46 sorties/std dev 23/5.9 losses/std dev
MOB/DOL	5150/79	5110/91 sorties/std dev
Aircraft in open	31/9.1	35/10.4 losses/std dev
MOB/DOL	5340/43	5305/55 sorties/std dev
Revetments	20/5.2	24/6.5 losses/std dev

EXCURSIONS

Fixed Proportion of Aircraft Remaining on Base

For these runs (shown in Table 5.8) the aircraft on base during attack was fixed at 0.5 for DOLs and 0.7 for MOBs. It appears that the bimodal distribution originally chosen for the MOBs was clearly in their favor, especially in the heavy attack case where the elimination of this uncertainty resulted in a 6 percent loss of sorties and an 11 percent increase in aircraft lost. The run points out the value of escape in minimizing loss of aircraft and ultimately sorties.

Sortie Generation Rate Uncertainty

Table 5.9 illustrates the critical importance of returning a MOB to full sortie generation capability. In this run the sortie generation rate for the MOBs was set to vary between 1.0 and 3.0 uniformly. This was intended to reflect the uncertainty surrounding the Air Force's ability to return a base to operation after attack. The MOBs produce only 62 percent of nominal sorties. The MOB/DOL configurations retain 87 percent and 80 percent of their ability to generate sorties for the one and two regiment attacks, respectively. Mathematically, the results are unsurprising; however, they should serve to focus attention on the

Table 5.8

EFFECTS OF UNCERTAINTY ON SORTIES AND AIRCRAFT LOST
(FRACTION REMAINING ON BASE FIXED AT 0.5 FOR DOLS
AND 0.7 FOR MOBS)

Basing	Attack Size	
	One Regiment	Two Regiments
MOB	5310/20 12/2.8	4910/38 sorties/std dev 60/4.6 losses/std dev
MOB/DOL Aircraft in open	5280/41 15/5.0	5190/51 sorties/std dev 26/6.0 losses/std dev
MOB/DOL Revetments	5340/22 8/2.6	5250/32 sorties/std dev 19/3.6 losses/std dev

Table 5.9

EFFECTS OF UNCERTAINTY ON SORTIES AND AIRCRAFT LOST
(MOB SORTIE GENERATION UNIFORMLY DISTRIBUTED 1.0-3.0)

Basing	Attack Size	
	One Regiment	Two Regiments
MOB	3400/993 12/2.5	3370/1007 sorties/std dev 23/5.3 losses/std dev
MOB/DOL Aircraft in open	4680/597 4/1.0	4310/633 sorties/std dev 13/5.4 losses/std dev
MOB/DOL Revetments	4680/597 4/1.0	4340/617 sorties/std dev 10/3.4 losses/std dev

extreme importance of assumptions made regarding the regeneration capability of MOBs.

VI. POLICY CONSIDERATIONS AND RECOMMENDATIONS

Where the source of conflict is uncertainty, the individual will first increase his search for clarification of the consequences of alternatives already evoked. Failing in that, he will increase his search for new alternatives.

J. G. March and H. A. Simon

GENERAL

The previous section indicates that, when uncertainties are taken into consideration, the risks associated with the exclusive reliance on MOBs for the continued protection and operation of fighter aircraft may be considerably higher than might have been previously expected. The analysis also suggests that the risks of tactical dispersal may be somewhat lower than anticipated. However, such analytic findings, although interesting in themselves, are likely to have little real impact in the face of organizational impediments despite the quality of the analysis or the good intentions of the individuals within the Air Force. This section examines the constituencies within the Air Force involved with basing policy to better understand how alternatives to current policy can be brought up for consideration. Recommendations are made for further work that would allow a fuller understanding of the risks involved in tactical dispersal.

SOME RELEVANT ORGANIZATIONAL THEORY

The school of thought represented by Richard M. Cyert, James G. March, and Nobel Laureate Herbert A. Simon presents a view of behavior in large complex organizations that is useful in understanding the context in which the examination of issues such as basing policy occurs. According to Simon, large organizational structures have come into being (Simon, 1979)

to carry out the work of production and government...as machinery for coping with the limits of man's abilities to comprehend and compute in the face of complexity and uncertainty.

These organizations adopt

several procedures of rather general applicability...that transform intractable decision problems into tractable ones. One procedure...is to look for satisfactory choices instead of optimal ones. Another is to replace abstract, global goals with tangible subgoals, whose achievement can be observed and measured. A third is to divide up the decision-making task among many specialists, coordinating their work by means of a structure of communications and authority relations. All of these, and others, fit the general rubric of "bounded rationality"....

As Simon suggests would be the case, the Air Force has divided up responsibility for decisionmaking for complex issues among several organizations. Each one is composed of functional specialists seeking satisficing solutions to problems compatible with the goals and subgoals these units have established for themselves based on their perception of the more abstract notion of airpower. Basing policy fails to fall neatly within the boundaries of any of the established groups, hence its characterization as a policy orphan.

Cyert and March (1963) view organizations as composed of coalitions. These coalitions are not static but rather they change with different decision problems. They contend that "Organizations avoid uncertainty. They impose plans, standard operating procedures, industry traditions, and uncertainty absorbing contracts on the environment." They predict that in the face of uncertainty organizations will first strengthen current standard operating procedures in an attempt to minimize disruption. If the enhanced standard operating procedures do not eliminate the uncertainty, then a search for alternatives would occur.

ORGANIZATIONAL BEHAVIOR IN THE AIR FORCE

Like most large complex organizations, the Air Force is composed of numerous specialized groups, each having its own set of goals, subgoals, and preferred standard operating procedures. This is not to say that the individual members and organizations are not supportive of overall Air Force goals, but rather that they act within the constraints of

their perceptions of reality as influenced by their education, experience, and organizational incentives. In Simon's terminology they behave in a manner consistent with the notion of bounded rationality. Large policy shifts within the Air Force usually require coalition action from among these specialized groups. Five groups potentially concerned with basing policy can readily be identified.

The Operators

The group with the strongest personal and emotional interest in the characteristics of fighter aircraft consists of those men who fly and fight in them and their commanders. It is, after all, their lives that are on the line in combat. Their orientation is naturally toward the performance of the aircraft itself, and to a lesser extent to the support required to get the aircraft into the air. Since dispersal would likely to require additions to the weight and dimensions of any new fighter, pilots' natural posture is to oppose it. They tend to play down the threat to MOB's while simultaneously highlighting the (quite real) difficulties involved in conducting dispersed operations. Dispersal, even the limited notion of tactical dispersal studied here, would also be a major disruption to standard procedures controlling the targeting and launch of combat sorties that occur at the MOB's.

Pilots and their commanders treat Soviet threats quite paradoxically. They envisage the Russian Giant producing aircraft in the out-years that will clearly out perform current U.S. systems. In addition, as Lambeth points out (Lambeth, 1985), they engage in

the highlighting of worst cases in the most stressful potential theaters, and then designing our forces against the special requirements posed by those scenarios with insufficient concern for other, less demanding but more likely circumstances in which U.S. tactical airpower might become committed.

However, when it comes to Soviet capability to attack airbases in the future, Ivan the Dwarf appears. (Although perception of the threat by personnel stationed in theater and those in the CONUS changes from time to time, personnel stationed in operational theaters do hold stronger

perceptions of the airbase threat than do those stationed in the CONUS. However, the CONUS based Tactical Air Forces is normally lead on airbase and aircraft design policies.) The prevailing attitude seems to be that "Soviet munitions aren't very good and won't be much better in the future." This occurs despite reports of new weapons being introduced in Afghanistan; for example, Yossef Bodansky recently described a weapon, introduced in the summer of 1984 and designed to destroy built-up areas.

The size of the container resembles that of a 500 kg HE bomb. It is a combination of incendiary, anti-personnel and blast elements. The bulk of the material of the bomb comprises a combination of small anti-personnel shrapnels buried in a thick, dark brown material. This material seems to be a derivative of the "liquid fire" already in use in Afghanistan...dropped at extremely low altitudes it seems to be parachute-stabilized. The bomb explodes in mid-air...shrapnels and droplets formed from the brown material fly in all directions, The droplets ignite on impact and burn profusely for days.

He also reports a second type of incendiary containing magnesium and phosphor rods that "produced sufficient heat to melt stone" (Bodansky, 1985).

March and Simon would characterize this type of behavior as "uncertainty absorption." Perrow explains this concept as follows (Perrow, 1979):

An organization develops a set of concepts...this permits easy communication. Anything that does not fit into these concepts is not easily communicated. For the organization, "the particular categories and schemes of classification it employs are reified, and become, for members of the organization, attributes of the world rather than mere conventions." This is especially apparent when a body of information must be edited and summarized to make it fit into the conceptual scheme - to make it understandable. The inferences from the material rather than the material itself are transmitted. The recipient can disbelieve the "facts" that are transmitted to him, but he can rarely check their accuracy unless he himself undertakes the summarization and assessment. This gives personnel who are in direct contact with the information considerable discretion and influence. They "absorb" quantities of "uncertainty."

The Technologists

This group draws its members from the program management and engineering communities, both military and civilian, who belong to the Air Force Systems Command (AFSC) and its functional representatives on the Air Staff. Although there is some crossfeed between the operational commands and AFSC, most members of this group come through the program management ranks. Since project management is a highly complex task where experience can pay big dividends, this specialization is somewhat understandable. The problem is that, in its isolation, this group focuses on air vehicle performance, along with program cost and schedule. There is little awareness of support requirements, much less threats to airbases. In fact, the existence and continued operation of airbases is generally taken as a given, that is, a standard operating procedure. Air vehicle performance is of course measured according to the stated preferences of the operations community to the extent this can be accommodated by the current contract. Any attempts to reevaluate basing policy is disruptive to this group also.

The Supporters

The airmen in the field turning the wrenches, delivering the spares, and pumping the fuel, their officers, and the thousands of civilians and military in the Air Force Logistics Command belong to this group. Basically, at all but the highest levels, they have little interest and even less influence in the requirements process. They belong to service organizations and, except for the few in forward based units, are conditioned to a peacetime industrial view of doing business, often constrained by limited budgets and nonproductive demands on manpower, creating a focus of attention on peacetime efficiency rather than combat resiliency. They fight their war continually, or so at least it seems.

The Contractors

Although not part of the Air Force, these organizations play an integral role in the development of any new weapon system. They are in a profitmaking business and are not likely to alienate their chief customers, the operators and the technologists. Their interest is in keeping or expanding their share of the pie. There is little incentive for them to challenge assumptions regarding the viability of MOB operations.

The Military Bureaucrats

This admittedly unkind label is applied to the manpower, personnel, and training communities. All headquartered in the CONUS, these groups function largely in isolation of the combat concerns of the service. Any change in the way Air Force units assign or train people causes such turmoil in this group that they are more prone than most to prefer the status quo. Since changes to those basing concepts currently in effect will change their accustomed ways of doing business, they too tend to resist change. (A recent notable exception to this harsh view involves a long-term program to consolidate job skills known as Rivet Workforce¹ which, if successful, should reduce the manning difficulties involved in dispersing.)

Summary of Organizational Behavior in the Air Force

Followers of the school of organizational theory called Neo-Weberian by Perrow (1979) should be gratified at how well their model predicts Air Force behavior. The growth of the Soviet threat has been recognized, thus setting up uncertainty regarding Air Force ability to sustain combat operations. As predicted by the model, Air Force response was to strengthen standard operating procedures; bases in USAFE have been toned down, hardened, and otherwise made more combat serviceable. In addition, the Airbase Survivability Program Office has been formed to further toughen MOBs. Predictably, its charter restricts

¹Rivet Workforce is a program aimed at combining Air Force Specialty Codes, thus reducing the proliferation of specialists required to maintain a given aircraft type.

it to work on MOB's; it does not evaluate alternatives. The Air Force recently held an exercise to demonstrate current concepts for improved MOB survivability. The disappointing results of the rapid runway repair procedures demonstrated may serve to enhance the uncertainty. Analysis such as that contained in this study can provide further evidence which, so the theory predicts, will assist in coalition building necessary to initiate a search for alternative solutions such as tactical dispersal.

OTHER CONSIDERATIONS

Cost is an important consideration in any policy-related issue. The approximate increase to the ten year life cycle cost for an aircraft capable of dispersing compared to a STOL capable MOB based airframe was estimated at about 10 percent by Berman et al. (1985). However, this estimate did not include the purchase price, lease costs, or other arrangements that would have to be made with owners of the land on which the DOLs would be located. Funds for the physical improvements that would be necessary for DOL sites could come from the NATO infrastructure monies currently used to harden COBs. Some portion of the shelter program money for each COB could be allocated to a DOL operating surface program.

IMPLEMENTATION

Dispersal presents a significant number of difficult implementation problems. One leading example of how the Air Force is attempting to deal with such problems is their Rivet Workforce program. This program will attempt to change the structure of the aircraft maintenance force over a five year period.

Another implementation problem has to do with institutional inertia both within the Air Force and among NATO allies.

The acquisition of land to use for DOLs would have to be considered a major problem, although many DOLs could employ the Autobahn System. Land use in Europe is a highly political issue. Although the agricultural surplus problem of the Common Market nations is similar to our own, so is the amount of political clout wielded by agricultural interests. In addition, any move obviously related to preparation for war is likely to bring about resistance from activists. Crafting an

acquisition program that would bring such potential opponents into agreement, or at least tacit acquiescence, would indeed be a major task.

SUMMARY AND RECOMMENDATIONS

The Air Force recognizes and is attempting to deal with, in a straightforward and conventional manner, the near-term threats represented by unguided unitary warhead weapons, CBUs, antipersonnel mines, chemicals, and Spetsnaz. It can be argued that these threats are affecting the design of future aircraft; i.e., STOL seems likely for the Advanced Tactical Fighter (ATF). These threats are also affecting the design of bases through various hardening programs. They have not yet influenced either organizational structures or command and control capabilities to any significant degree, except that emphasis is being placed on base ground defense, in view of the threats from wartime Spetsnaz and terrorists.

Future threats, such as sophisticated integrated airfield attack systems, have not influenced base design, aircraft design, organizational structures, or command and control. This is important because such weapons, and perhaps even current weapons, could make fixed base structures untenable for extended periods of time. The Air Force has not come to grips with these potential threats for a number of reasons:

- The threat of future weapons is only potential, whereas the money needed to deal with them is concrete and proximate in time.
- The penalty to aircraft performance that may be necessary to deal with these threats will remain whether or not the threat ever materializes.
- Current aircraft will be in the inventory well into the 21st century and ways must be found to protect them regardless of what happens in the arena of new aircraft development.
- The methods proposed to deal with these threats work against the goals and perceptions of the major constituencies within the service and are themselves of uncertain effectiveness.

- The window of opportunity for change provided by the design of a new aircraft (ATF) is brief and comes along infrequently. Whether this window coincides with the presence of an integrative coalition of decisionmakers with the personality, ability, time, and authority to investigate change is a matter of chance.

Significant change in basing concepts is unlikely to occur without a change in the perceptions of Air Force leadership. Such a change is unlikely to occur on the sole basis of arguments such as this Note presents. The data of Sec. IV can only serve to quantify what most concerned individuals already know. This dilemma can be broken through efforts to develop experimental evidence for the base vulnerability controversy. The specific policy recommendation of this Note is that a program be established to empirically test the types of assumptions used to drive airbase simulation models such TAGS, TSARINA, and TSAR. Management of such an effort should be outside the existing organizational structure, to insure independence of thought and action. Reporting should be directly to the Air Force Chief of Staff. Specific items to be tested would include:

- The ability of the civil engineering community to conduct Rapid Runway Repair operations on enough real craters to establish reasonable confidence in their capability. These craters should be the product of weapons dropped from the air and should include craters produced by Soviet weapons, if possible, as well as the likes of JP 233, BKEP, and STABO. Aircraft should then operate from the repaired surfaces to insure the viability of the repairs.
- The degree of protection provided by shelters against current and potential threat weapons. Again delivery should be from the air and not by rocket sled or any other artificial means. Revetments and covered revetments should also be included in such tests.

- Clearance techniques for sophisticated minefields.
- Detection of DOL type operations in environments similar to Central Europe.
- Penetration to DOL sites in the face of active defenses in Red Flag type exercises.
- The delivery of weapons on DOL targets in operationally realistic conditions.

How to base aircraft in the future is such a fundamentally important question to the Air Force that expenditures of the nature implicit in these recommendations are not unreasonable. Without such hard data it is not likely that a strongly held belief, such the viability of the current basing posture, can be successfully challenged.

It is hoped that the methodology demonstrated by this Note can serve as a guide to future work in the sortie survivability area. In warfare both risk and uncertainty are unavoidable, and evaluations that ignore this reality stand the chance of implicitly accepting far greater risks than prudent or necessary.

Appendix

TAGS AIR WARFARE INPUT DATA LISTING

Array	Element	Usage	Definition
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AIR WARFARE LOGIC OPTION

A	330		Switch: If unity, the air-warfare logic will use CALCB and CALCP to permit several aircraft types to be represented and several special options to be used.
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AIRCRAFT NUMBERS

A B	1	M*	Inventory of fighter class aircraft.
A B	2	M*	Inventory of attacker class aircraft.
A B	3	M*	Inventory of bomber class aircraft.
A B	259	*	Current number of friendly fighters in sanctuaries.
A B	260	*	Current number of friendly attackers in sanctuaries.
A B	261	*	Current number of friendly bombers in sanctuaries.

AIRCRAFT NUMBERS BY TYPE (See App. C for definitions when CALCB and CALCP are not used)

A B	150	}	t(d)	Fighter fraction of type AF1 or BF1
A B	151			Fighter fraction of type AF2 or BF2
A B	152			Fighter fraction of type AF3 or BF3
A B	155	}	t(d)	Attacker fraction of type AA1 or BA1
A B	156			Attacker fraction of type AA2 or BA2
A B	157			Attacker fraction of type AA3
A B	158	}	t(d)	Attacker fraction of type AA4
A B	160			Bomber fraction of type AB1 or BB1
A B	161			Bomber fraction of type AB2 or BB2

REINFORCEMENT RATES

A B	118	}	D*	Daily rate for fighter (AF1 or BF1) aircraft brought into the theater
A B	119		D*	Daily rate for attacker (AA3 or BA1) aircraft brought into the theater
A B	120		D*	Daily rate for bomber (AB1 or BB1) aircraft brought into the theater
A B	269	}	*	Augmentation per day of friendly fighters in sanctuaries
A B	270		(e)*	Augmentation per day of friendly attackers in sanctuaries
A B	271		*	Augmentation per day of friendly bombers in sanctuaries
A B	26	}	U	Daily rate for AB2 or AF3 aircraft brought into the theater
A B	39		U	Daily rate for AF2 or BA2 aircraft brought into the theater
A	313		U	Daily rate for AA2 aircraft brought into the theater

SPECIAL MOD - AB2 FILLERS

A	301	T	Switch: Mod. operative if unity
A	303	C	Number of AB2s initially withheld as filler aircraft
A	304	C	Total daily AB2 reinforcement to the theater plus to the filler group

AIR BASE DATA

NUMBER OF AIRFIELDS BY CLASS

A B	20	M	Number of friendly fighter aircraft airfields
A B	21	M	Number of friendly attacker aircraft airfields
A B	22	M	Number of friendly bomber aircraft airfields

Array	Element	Usage	Definition
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NUMBER OF SHELTERS BY CLASS

A B	256	M*	Number of friendly fighter shelters
A B	257	M*	Number of friendly attacker shelters
A B	258	M*	Number of friendly bomber shelters

SPECIAL ALLOCATION OPTIONS

A B	30		Ratio of friendly escort sorties per deep penetrator to escort sorties per CAS sortie
A B	15		The expected number of nonaborted enemy air defense aircraft that are prevented from engaging an escorted friendly sortie by a single friendly escort aircraft
A	70	U	Fraction of the potential AB1, AA2, and AB2 sorties assigned to attack enemy airfields (priority in order noted)
B	70	U	Fraction of the potential BA2 sorties assigned to attack enemy airfields
A	100	U	Fraction of the AF1 sorties to be allocated to the escort mission (remainder air defense)
B	100	U	Fraction of the BF2 sorties to be allocated to CAS (remainder air defense)
B	302	U	Fraction of the RED attacker aircraft to be used for air defense (use optional; once used, set to 0.0001 for zero)
A	388	U	Fraction of the AF2, AA2, and AB2 non-ABA sorties to be allocated to CSAM
B	388	U	Fraction of the BF2, BA2, and BB2 non-ABA sorties to be allocated to CSAM
A	389	U	Fraction of the AF2, AA2, and AB2 non-ABA sorties to be allocated to interdiction
B	389	U	Fraction of the BF2, BA2, and BB2 non-ABA sorties to be allocated to interdiction
A B	320		Fraction of the CSAM sorties flown in CAS zone
A	311	U	Fraction of the AB2 CAS sorties to be assigned for recce
B	311	U	Fraction of the BA2 CAS sorties to be assigned for recce

SORTIE FACTORS

A B	144	M	Fraction of current friendly aircraft inventory that are combat ready
A B	40	M	Fraction of friendly sorties that do not abort
A B	134	MD	Sorties per combat-ready friendly aircraft (AB1 or BB1) per day for sustained operation on an airfield strike
A B	135	M	Sorties per combat-ready friendly aircraft per day for sustained operation on an interdiction mission
A B	136	MD	Sorties per combat-ready friendly aircraft per day for sustained operation on a CAS mission (and for AB2 and BB2 on ABA missions)
A B	137	M	Sorties per combat-ready friendly aircraft per day for sustained operation on an air defense mission
A B	138	M	Sorties per combat-ready friendly aircraft per day for sustained operation on an air escort mission
A B	230	M	Sorties per day per combat-ready friendly aircraft for sustained operation on a counter-SAM mission
A	193	U	Used to increase AF2 CAS sortie rate to $[A(136) + A(193)]$

LOSSES

NON-COMBAT

A B	114		Fraction of friendly fighter sorties lost for reasons other than enemy action
A B	9		Fraction of friendly attacker sorties lost for reasons other than enemy action
A B	10		Fraction of friendly bomber sorties lost for reasons other than enemy action

Array	Element	Usage	Definition
AAA-LOSSES			
A B	67		Fraction of nonaborted friendly offense fighter sorties lost to enemy anti-aircraft fire
A B	68		Fraction of nonaborted friendly offense attacker sorties lost to enemy anti-aircraft fire
A B	69		Fraction of nonaborted friendly offense bomber sorties lost to enemy anti-aircraft fire
AIRFIELD ATTACKS			
UNSHeltered AC DATA			
A B	23		Fraction of friendly aircraft inventory parked on friendly airfields during an enemy airfield strike.
A B	312		Fraction friendly aircraft not in assigned shelters.
A B	168	D	Expected number of killing hits by conventional weapons on enemy parked aircraft inflicted by a friendly fighter (AB2) sortie successfully attacking enemy airfields.
A B	169	D	Expected number of killing hits by conventional weapons on enemy parked aircraft inflicted by a friendly attacker (AA2) sortie successfully attacking enemy airfields.
A B	170	D	Expected number of killing hits by conventional weapons on enemy parked aircraft inflicted by a friendly bomber (AB1) sortie successfully attacking enemy airfields.
A B	318		Nominal assumption re unsheltered enemy aircraft per airfield (default = 20)
A B	319		Exponent used in empirical degradation of friendly ABA attacks on unsheltered AC
SHELTERED AC DATA			
A B	262	D	Expected number of enemy shelters hit by one effective friendly fighter counter-air (AB2) sortie (aircraft killed if present).
A B	263	D	Expected number of enemy shelters hit by one effective friendly attacker counter-air (AA2 or BA2) sortie (aircraft killed if present).
A B	264	D	Expected number of enemy shelters hit by one effective friendly bomber counter-air (AB1 or BB1) sortie (aircraft killed if present).
A B	314		Probability friendly shelter destroyed if shelter hit. Only surviving shelters targeted if >0; all targeted if <0
AIRFIELD DEFENSES			
A B	222		Probability that a hostile fighter aircraft is destroyed while attacking a friendly airfield.
A B	223		Probability that a hostile attacker aircraft is destroyed while attacking a friendly airfield.
A B	224		Probability that a hostile bomber aircraft is destroyed while attacking a friendly airfield.
A B	316		Nominal number of friendly ABA sorties per enemy airfield (default = 20)
A B	317		Exponent used for empirical variation of friendly airfield defense effectiveness
SANCTUARY ATTACK OPTION			
A B	321	U+	Switch: Friendly type #1 bomber usable against enemy sanctuary when set to 1.
A B	322	C	Fraction friendly AB1 or BB1 sorties allocated to sanctuary attack.
A B	323		Number of bomber shelters in sanctuary.
A B	326	C	Fraction nominal ABA effectiveness vs unsheltered sanctuary AC.
A B	327	C	Fraction nominal ABA effectiveness vs sheltered sanctuary AC.

MOB	3400/993 12/2.5	3370/1007 sorties/std dev 23/5.3 losses/std dev
MOB/DOL	4680/597	4310/633 sorties/std dev
Aircraft in open	4/1.0	13/5.4 losses/std dev
MOB/DOL	4680/597	4340/617 sorties/std dev
Revetments	4/1.0	10/3.4 losses/std dev

extreme importance of assumptions made regarding the regeneration capability of MOBs.

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Array	Element	Usage	Definition
AIR DEFENSE			
A B	29		Fraction of friendly air defense sorties that are positioned to engage enemy CAS sorties.
A B	395		Relative likelihood of forward air defense aircraft sighting deep/shallow intruders.
A B	48		Probability air defense sortie detects intruder (only for forward area if values specified for rear)
A B	394		Probability air defense sortie detects in rear area.
A B	315		Fraction interceptions sustained before munitions expended
P_k's			
A B	32	D	Probability of a friendly air defense fighter (AF3 or DF1) attacking and killing an enemy offense fighter aircraft after air-to-air contact has been made.
A B	33	D	Probability of a friendly air defense fighter (AF3 or BF1) attacking and killing an enemy offense attacker aircraft after air-to-air contact has been made.
A B	34	D	Probability of a friendly air defense fighter (AF3 or DF1) attacking and killing an enemy bomber (BB2 or AB2) aircraft after air-to-air contact has been made.
A B	41	U	Air defense effectiveness multiplier for AF1 or BA1 aircraft.
B	193	U	Air defense effectiveness multiplier for BF2 aircraft.
9	305	U	Ratio of air defense P _k vs AB1 to that vs AB2 (default = 1, use 10 ⁻⁶ for 0).
B	308	U	Ratio of air defense P _k vs BB1 to that vs BB2 (default = 1, use 10 ⁻⁶ for 0).
JETTISON			
A B	393		Fraction of pilots that jettison payload when detected.
A B	392		Ratio of air defense kill probability against enemy aircraft that have jettisoned payload to that for those that have not (default = 1; use 10 ⁻⁶ for 0)
COUNTER AIR DEFENSE			
A B	35		Probability of an enemy air defense aircraft being killed by a friendly offense aircraft that has jettisoned its munitions.
A B	391		Ratio probability of killing enemy interceptor if payload has not been jettisoned to that when it has (default = 1, use 10 ⁻⁶ for 0).
DAMAGED AIRCRAFT			
A B	65		Ratio of the number of damaged friendly fighter aircraft to the number of friendly fighter aircraft destroyed in air combat.
A B	61		Ratio of the number of damaged friendly attacker aircraft to the number of friendly attacker aircraft destroyed in air combat.
A B	62		Ratio of the number of damaged friendly bomber aircraft to the number of friendly bomber aircraft destroyed in air combat.

Array	Element	Usage	Definition
SAM DEFENSES			
A B	218	*	Total number of active friendly SAMs.
A B	220	*	Number per day of friendly SAMs brought into the theater.
A B	105		Fraction friendly SAM in forward (CAS) zone.
A B	110	C210	Fraction friendly SAM per penetration corridor.
A B	111		Maximum engagements per day per friendly SAM unit.
A B	213		Probability a friendly SAM engages a non-CAS sortie (= ratio of coverage width to corridor width)
A B	214		Probability a friendly SAM engages a CAS sortie (= ratio of intruder swept area to CAS ops area)
A B	215		SAM P_k vs enemy penetrator.
A B	210		Fighter CSAM P_k .
A S	211		Attacker/fighter CSAM P_k s.
A B	212		Bomber/fighter CSAM P_k s.
A E	225		Enemy fighter CSAM sortie P_k by friendly SAM
A B	226		Enemy attacker CSAM sortie P_k by friendly SAM
A B	227		Enemy bomber CSAM sortie P_k by friendly SAM
A B	255		Ratio damaged/destroyed friendly SAM
A B	221		Friendly SAM repair rate

AIRCRAFT A-BOMB ATTACKS

A B	4		A-bomb stockpile
A B	145		Daily A-bomb commitment on enemy fighter airfields
A B	146		Daily A-bomb commitment on enemy attacker airfields
A B	147		Daily A-bomb commitment on enemy bomber airfields
A E	36		Fraction friendly fighter killed per A-bomb
A E	37		Fraction friendly attacker killed per A-bomb
A E	38		Fraction friendly bomber killed per A-bomb
A B	149		Daily A-bombs for CAS
A E	25		Expected number enemy troop units sighted and killed per A-bomb
A B	148		Daily A-bombs for INTERDICTION
A B	26		Reciprocal A-bombs/day to reduce supply capacity to one-half

CLOSE AIR SUPPORT

EFFECTIVENESS

A B	63	D	Fraction of a hostile division killed by a successful fighter (AF2 or BF3) sortie
A B	64	L	Fraction of a hostile division killed by a successful attacker (AA1 or BA2) sortie
A B	65	D	Fraction of a hostile division killed by a successful bomber (AB2 or BB2) sortie
A B	95	L	Fraction of a hostile division killed by a successful AA2 or BF2 sortie
A	96	U	Fraction of a hostile division killed by a successful AA3 sortie

Array	Element	Usage	Definition
OTHER FACTORS			
A B	200		Fraction of the friendly theater CAS kill potential to be used in the sector under study
A B	122	U	Exponent used in an empirical relation used to degrade CAS effectiveness estimates (see CALCR)
A	309	U	Maximum number of improved Blue CAS weapons (default 10^{10})
B	307	+	When set =1, is varied with ground defense mode, to control CAS effectiveness values
INTERDICTION DATA			
A B	27		Reciprocal of fighter sorties required to reduce enemy capacity to one-half.
A B	390		Fraction of the interdiction effort to be allocated to the sector under study.
A B	11		Equivalent fighter sorties per attacker interdiction sortie.
A B	13		Equivalent fighter sorties per bomber interdiction sortie.
A B	115		Interdiction time lag in days.

NOTES:

- (a) These conditional factors are mandatory if FEBAV is not used (i.e., if B(396) = 0).
- (b) The switch controlling the mass and breakthrough logic is of a special nature: The integer part of the input value is interpreted as the number of days over which the attack on a prepared/deliberate defense is sustained; the fractional part is identified as the factor K in the relation $F^k = F + K \cdot X \cdot D$ (see p. 32).
- (c) If FORCES is in use (i.e., if B(330) = 1), one of these two constraints must be specified; if both are specified, B(313) cancels B(351).
- (d) These fractions must sum to unity, or the computation will be cancelled in CALC.
- (e) These definitions apply when the CALCB and CALCR routines are in use (i.e., when A(330) = 1). Whenever any one of the aircraft types (other than those specified by 118, 119, or 120) is reinforced, the reinforcement rates for all other members of its class must be redefined on the following day(s).

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